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STOCHASTIC CONCEPTS EVALUATION MODEL - PHASE III (STOCEM-3)

JUNE 1993

PREPARED BY
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13. ABSTRACT (Maximum 200 words)

The Concepts Evaluation Model (CEM) is a computer simulation model of theater land and air warfare that is fully automated and deterministic, yielding a single outcome for any situation simulated. In previous projects, stochastic versions of the CEM were developed that make use of individual replications of stochastic attrition input data and that simulate certain CEM processes based on statistical distributions rather than entirely on expected values. In this project (Phase III), refinements were made to the stochastic treatment of processes in the CEM, and statistical analyses were conducted to determine whether the distribution of results of the stochastic CEM (STOCEM) using deterministic attrition assessment is the same as the distribution of results of the STOCEM using stochastic assessment of attrition, and to estimate how many STOCEM replications would be required for acceptable confidence intervals based on a current Korea scenario.

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CAA (Concepts Analysis Agency, United States Army)	STOCHASTIC CONCEPTS EVALUATION MODEL - PHASE III (STOCEM 3)	SUMMARY CAA-TP-93-2

THE REASONS FOR PERFORMING THIS RESEARCH AND ANALYSIS ACTIVITY (RAA). Demonstrate the capability to conduct useful analysis using the Stochastic Concepts Evaluation Model (STOCEM) for future study requirements. Demonstrate the presentation of results in a manner that illustrates the advantages of a stochastic theater-level simulation; i.e., show the range and distribution of possible outcomes for a given scenario.

THE SPONSOR is the Director, US Army Concepts Analysis Agency, 8120 Woodmont Avenue, Bethesda, MD 20814-2797.

THE OBJECTIVES were to:

(1) Improve the STOCEM.

(2) Demonstrate the feasibility of stochastic simulation of a realistic Korean scenario.

(3) Compare stochastic (STOCEM) with deterministic Concepts Evaluation Model (CEM) results.

(4) Estimate the number of STOCEM replications required for acceptable confidence intervals.

(5) Test whether STOCEM results using individual replications of the Combat Sample Generator (COSAGE) for assessing attrition are distributed the same as STOCEM results using the average of COSAGE replications.

THE SCOPE OF THE RAA. A Korea scenario of 40 days of warfare was used for conducting all the simulations of the analysis reported here. Conclusions and insights about the STOCEM do not necessarily extend to simulations other than the particular scenario simulated.

THE MAIN ASSUMPTIONS. It is assumed that the probability distributions used in the STOCEM provide a realistic representation of the variability of the selected stochastic processes.

THE BASIC APPROACH

(1) Update the STOCEM with the latest improvements of the CEM. Enhance the validity of the STOCEM by improving the implementation of stochastic processes, to include the rate of advance of engaged maneuver forces.

(2) Using graphical and statistical techniques, compare the results of the STOCEM with deterministic CEM results.

(3) Estimate the number of STOCEM replications required for acceptable confidence intervals by applying Student's t-variable.

(4) Apply Kolmogorov-Smirnov tests to determine whether STOCEM results using individual replications of the COSAGE for assessing attrition are distributed the same as STOCEM results using the average of COSAGE replications.

THE PRINCIPAL FINDINGS

(1) In the 1992 Korea scenario used for this RAA, no more than 12 replications of the STOCEM are required to obtain acceptable confidence intervals for the outcome measures examined. The computer resources needed to apply the STOCEM to Korea campaign analyses are available.

(2) In this scenario, some results of STOCEM simulations are statistically significantly different from the deterministic CEM simulation results.

(3) The STOCEM results using deterministic assessment of attrition are statistically significantly different from the STOCEM results using stochastic assessment of attrition.

(4) The results of STOCEM using deterministic assessment of attrition are closer to the results of CEM than are the STOCEM results using stochastic assessment.

RAA IMPACT. This research effort refined and expanded the stochastic representation of processes in the STOCEM. It demonstrated the reporting and graphic display of results of STOCEM replications. It determined the required number of replications of the STOCEM; and it showed that STOCEM outcomes are significantly affected by the choice of deterministic versus stochastic assessment of attrition. This effort shows the STOCEM to be a valuable simulation tool, ready to apply to important Army analyses.

THE RAA was undertaken by Dr. Ralph E. Johnson and Mr. William T. Allison, Research and Analysis Support Directorate.

COMMENTS AND QUESTIONS may be sent to the Director, US Army Concepts Analysis Agency, ATTN: CSCA-RSD, 8120 Woodmont Avenue, Bethesda, MD 20814-2797.

START AND COMPLETION DATES OF RAA. Jan 93 - Jun 93

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CHAPTER 1

EXECUTIVE SUMMARY

1-1. BACKGROUND

a. Because of the large size and long computer execution time of many theater-level campaign simulations, these models have been restricted to deterministic processes, so that only one replication is required for a given scenario. The Concepts Evaluation Model (CEM) is one example of an extensively employed theater-level model that has remained deterministic due to computer resource constraints. In recent years, however, the availability of fast computers and supercomputers have reduced execution time so much that it is feasible to conduct multiple replications of the theater-level simulations.

b. Beginning in 1991, CAA has initiated a series of studies to explore the possibilities and performance characteristics of a stochastic simulation model of theater warfare, called STOCEM, based on the CEM.

1-2. PROBLEM

a. One problem is that the present use of deterministic results does not afford the analytical insights obtainable from stochastically produced outcomes. The usual method of applying the CEM in a study is to develop the best available estimate of all CEM input data, yielding a single point estimate of each CEM output value. These results are then presented as the expected campaign outcome in briefings and written reports. Stochastically modeled processes within the CEM can produce a distribution of CEM outcomes that provide decisionmakers and analysts a greater appreciation of the risks associated with specific scenarios.

b. Another problem is that nonmonotonic behavior or "structural variance" has occurred in the CEM, stemming from the use of decision thresholds; a slight increase in strength of one side may alter the force ratio that is compared to a decision threshold, resulting in a different allocation of forces and a significantly different outcome (Reference 1).

1-3. PURPOSE. The purpose of this research analysis activity (RAA) is to improve, test, and analyze the tools available for stochastic modeling of theater level warfare.

1-4. OBJECTIVE

a. Improve the STOCEM.

b. Demonstrate the feasibility of stochastic simulation of a realistic Korean scenario.

c. Compare stochastic (STOCEM) with deterministic (CEM) results.

d. Estimate the number of STOCEM replications required for acceptable confidence intervals.

e. Test whether STOCEM results using individual replications of the Combat Sample Generator (COSAGE) Model for assessing attrition are distributed the same as STOCEM results using the average of COSAGE replications.

1-5. SCOPE. Testing and analysis of the STOCEM was conducted using simulations of a current 40-day Korea scenario. No changes were made to the deterministic CEM inputs in the analysis reported here.

1-6. ASSUMPTIONS. The enhancements to the CEM require assumptions concerning the representation of certain stochastic processes by predetermined probability distributions.

a. Both sides' army, corps and division decision thresholds can be represented by beta distributions.

b. The hasty/prepared defense decision threshold can be represented by a beta distribution.

c. The probability of nonrepairable destruction given a combat-damaged vehicle can be represented by a binomial distribution.

1-7. LIMITATIONS. Conclusions and insights about the behavior of the stochastic CEM do not necessarily extend to simulations other than the particular Korea scenario used for this study.

1-8. STUDY APPROACH

a. Update the STOCEM with the latest improvements of the CEM. Enhance the validity of the STOCEM by improving the probability distributions of certain stochastic processes and expanding the stochastic processes to include the rate of advance of engaged maneuver forces.

b. Using graphical and statistical techniques, compare the results of the STOCEM with deterministic CEM results.

c. Estimate the number of STOCEM replications required for acceptable confidence intervals, by applying Student's t-variable.

d. Apply Kolmogorov-Smirnov tests to determine whether STOCEM results using individual replications of the COSAGE for assessing attrition are distributed the same as STOCEM results using the average of COSAGE replications.

1-9. ESSENTIAL ELEMENTS OF ANALYSIS (EEAs)

a. How do the results of stochastic simulation of a Korean campaign compare with deterministic CEM results?

ANSWER: For many of the outcome measures examined the result of the CEM is outside the 90 percent confidence interval and outside the range of the distribution of results of the STOCEM.

b. How many replications of the STOCEM are required to obtain acceptable confidence intervals on the outcome measures of interest for this Korea scenario?

ANSWER: No more than 12 replications are required for 90 percent confidence intervals no wider than 1/10 of the mean values of the outcome measures examined. No more than 10 replications are required for 99 percent confidence intervals no wider than 1/5 of the mean values of the outcome measures examined.

c. Are the results of the STOCEM using deterministic assessment of attrition the same as the results of the STOCEM using stochastic assessment of attrition?

ANSWER: No, for many of the outcome measures examined the distribution of results of the STOCEM using deterministic assessment of attrition (average combat sample) are statistically significantly different from the distribution of results of the STOCEM using stochastic assessment (individual replications of the COSAGE).

1-10. RECOMMENDATIONS

a. Replications Required. From the analysis of the STOCEM results reported here, it is recommended that no more than 12 and no fewer than 5 replications of STOCEM are executed for any one scenario, depending on which CEM outcome measures are to be used in the analysis.

b. Applications. It is recommended that the STOCEM be applied in future campaign analyses as the base case. By generating STOCEM replications as a base case, it can be determined statistically whether excursions and varying assumptions produce significantly different outcomes. Of course, the range and distribution of possible outcomes of the baseline situation will also be a product of the STOCEM replications.

c. Further Testing

(1) CAA should conduct further analysis of the ATCAL assessment process in the STOCEM, to explain the significant differences between the distributions of STOCEM results using stochastic versus deterministic assessment of combat engagements. Testing of the STOCEM should be conducted using the Ardennes Campaign data base so that it can be determined whether stochastic or deterministic assessment yields simulation results that are more consistent with historical records.

(2) Testing should examine the effects on distributions of STOCEM results of (a) the quantity of replications of the COSAGE; (b) the quantity of replications of the STOCEM; and (c) the variance of the distributions assumed in the STOCEM decision processes.

(3) As nonmonotonic or counterintuitive results of the CEM are found, the same simulations should be executed using the STOCEM, to determine whether the use of stochastic simulation eliminates the nonmonotonic results.

CHAPTER 2

INTRODUCTION

2-1. BACKGROUND

a. A principal mission at the US Army Concepts Analysis Agency (CAA) is to conduct analysis of the capabilities and requirements of forces engaged in warfare at the theater level). Foremost among the many applications used by CAA to quantitatively ascertain the "capabilities and requirements" from the inherent complexities of combat is the CEM. Developed at CAA, the CEM is a low-resolution, two-sided, closed, deterministic, theater-level computer simulation utilized extensively for both long-term and quick reaction Army-level studies. Along with other simulation models, the CEM is used to provide comprehensive analytical support to numerous Army organizations, to include the Offices of the Deputy Chief of Staff for Operations and Plans , Deputy Chief of Staff for Logistics, Deputy Chief of Staff for Personnel, and various major Army commands.

b. The deterministic nature of the CEM has led to a standard study technique of resolving a base case from which numerous excursions and variations are completed. The usual method of applying the CEM in a study is to develop the best available estimate of all CEM input data, yielding a single point estimate of each CEM output value. These results are then presented as the expected campaign outcome in briefings and written reports. This methodology has proven to be a sound basis for the analytical findings using a deterministic model. However, a determinist simulation is constrained from providing a range of possible outcomes in any given scenario or specific excursion. The analysis and presentation of the risks associated with assuming a specific outcome of combat are next to impossible using these standard methodologies and deterministic simulation models.

c. In June 1991, CAA initiated a study to resolve the feasibility of stochastically enhancing the current version of CEM. This study was motivated partly by an April 1990 workshop at the Naval Postgraduate School on Stochastic Architecture for Theater-Level Modeling. The workshop concluded that "analyses of the scenarios that appear likely for the next few years require stochastic models that can properly account for uncertainty and variation" (Reference 2, p 9-10).

d. For purposes of this report, a stochastic simulation can be understood to mean a model "that uses random variables defined within a common sample space" (Reference 3, p 153).

e. The initial CAA study, entitled A Stochastic Version of the Concepts Evaluation Model, was intended to determine the feasibility and verify the results of a stochastic model, STOCEM, based on the CEM. In this preliminary study, the following significant findings were established.

(1) "The execution time of a replication of Stochastic CEM was not appreciably greater than that of deterministic CEM" (Reference 4, p 7-3). Based on the requirement to provide timely analysis, multiple replications of the STOCEM are a feasible alternative in many studies to the deterministic CEM.

(2) Ranges of possible outcomes were identified by the original study of STOCEM simulating the Ardennes campaign. The STOCEM "produced measures of

central tendency, such as mean and median, along with measures of variability, such as range, standard deviation, box plot or interquartile range to account for uncertainty and stochastic variation in the outcome results of theater-level campaign simulations" (Reference 4, p 7-3).

(3) "For many CEM outcome measures, the different versions of Stochastic CEM that have been developed produce results that represent significantly different populations" (Reference 4, p 7-3). The statistically significant differences observed in the initial study include ammunition consumption, average forward edge of the battle area (FEBA) movement, and artillery loss exchange ratios.

f. The second analysis of STOCEM (Reference 5), using a modern Iraq scenario, found that:

(1) No single stochastic process in the STOCEM is the greatest contributor to the variability observed in all of the different outcome measures of the STOCEM. Rather, a wide variety of the stochastic processes of the STOCEM are responsible for the variation in STOCEM outcome measures

(2) Ten replications of the STOCEM are sufficient for acceptable confidence intervals on the outcome measures examined in this scenario. The cost in computer resources of executing 10 STOCEM replications is not prohibitive.

(3) Further analysis of the methods to model and report stochastic variations in STOCEM is worthwhile, to enhance the realistic simulation of combat processes at the theater level and also provide decisionmakers and analysts greater insights into the risks associated with a specific scenario. In order to make the Stochastic CEM useful in CAA studies, additional modifications and refinements to the STOCEM and its postprocessors are desirable.

2-2. STOCHASTIC CEM PROCESSES. Prior to the research effort reported here, the latest version of the STOCEM permitted a user to treat each of the following CEM processes as either deterministic or stochastic, by input.

a. **Decision Thresholds.** The friendly/enemy force ratio thresholds used in the CEM to make decisions at army/Front, corps, and division headquarters, such as mission, commitment or reconstitution of reserves, assignment of sector boundaries to subordinates, and allocation to subordinates of general support artillery and close air support. In the deterministic mode, the force ratio is compared with a threshold, T, that is input. In the stochastic mode, the force ratio is compared with a threshold, T', that is drawn from a beta distribution (which was recommended by CAA statistical experts becvause of the beta distribution's finite interval and its flexibility in closely approximating practically any shape desired) with mean T on the subjectively selected interval (T/2, 2T), as follows:

$$T' = 0.5\ T(1 + 3\ \mathrm{RNBETA}(K, 2K))$$

where T' = the stochastically obtained decision threshold value,
T = the input value used as the mean of the distribution,
K = an input parameter that controls the variance of the beta distribution,

$$\mathrm{Variance}(T') = T^2/(6K + 2)$$

RNBETA is the IMSL routine for drawing random numbers from a beta distribution on the interval (0, 1).

b. Hasty/Prepared Defense Threshold. In the deterministic mode, the recent movement of the FEBA in a sector is compared with an input threshold H to determine whether a defender in the sector fights from "prepared" or "hasty" defenses. In the stochastic mode, FEBA movement is compared with a threshold value, H', drawn from a normal distribution with mean H and variance controlled by input. The use of the normal distribution to represent this process stochastically is not ideal, as will be discussed in paragraph 4-3.

c. Combat Samples. In the deterministic mode, the combat sample used for all assessments of attrition is an average of the replications of COSAGE for the appropriate posture. In the stochastic mode, for each subsector engagement, an individual replication of COSAGE for the appropriate posture is randomly selected as the combat sample to be used in assessing combat attrition.

d. Disposition of Losses

(1) In a subsector engagement, the quantity of combat-damaged vehicles of a particular type that are destroyed rather than repairable; the quantity of repairable damaged vehicles that must be abandoned because of adverse FEBA movement; the quantities of combat casualties of personnel that are wounded, of wounded that require hospitalization, and of hospitalized wounded that require evacuation from theater are calculated in the deterministic mode by multiplying the losses by an input fraction P.

(2) In the stochastic mode, a random number R is drawn from the uniform distribution U(0, 1). If R exceeds the input fraction P of Blue personnel combat casualties that are wounded, then none of the Blue combat casualties in the subsector engagement are wounded; if $R < = P$ then all the Blue combat casualties in the engagement are wounded. The other disposition decisions for personnel casualties and for damaged vehicles are made stochastically the same way. The STOCEM Phase III research refines the modeling of this stochastic process, as described in paragraph 4-3b.

e. The STOCEM is coded so that the user can select whether each of the above processes is to operate in the deterministic or stochastic mode. In particular, the user of STOCEM can select whether an average combat sample or an individual replication of COSAGE, randomly selected for each engagement, is used to assess combat attrition.

f. STOCEM Graphics. The figures appearing in Chapters 5 and 6 are products of a variety of software that has been developed for the analysis of results of multiple replications of a stochastic simulation.

2-3. PURPOSE. The purpose of this RAA is to improve, test, and analyze the tools available for stochastic modeling of theater-level warfare.

2-4. OBJECTIVE. Continue development of the Stochastic CEM by improving the implementation of certain stochastic processes in the STOCEM, and then test and analyze the performance of the STOCEM. Specifically, the objectives for the study are as follows.

a. Improve the Stochastic CEM, incorporating all the enhancements in the latest version of the CEM, refining the implementation of certain stochastic processes, and introducing a stochastic representation of the displacement of the FEBA due to maneuver unit engagements.

b. Demonstrate the feasibility of stochastic simulation of a realistic Korean scenario.

c. Compare stochastic (STOCEM) with deterministic (CEM) results.

d. Estimate the number of STOCEM replications required for acceptable confidence intervals.

e. Test whether STOCEM results using individual replications of the COSAGE for assessing attrition are distributed the same as STOCEM results using the average of COSAGE replications.

2-5. ASSUMPTIONS. The enhancements to the CEM require assumptions concerning the representation of certain stochastic processes by predetermined probability distributions.

a. Both sides' army, corps, and division decision thresholds can be represented by beta distributions.

b. The hasty/prepared defense decision threshold can be represented by a beta distribution.

c. The probability of nonrepairable destruction given a combat-damaged vehicle can be represented by a binomial distribution.

2-6. ESSENTIAL ELEMENTS OF ANALYSIS (EEAs)

a. How do the results of stochastic simulation of a Korean campaign compare with deterministic CEM results?

b. How many replications of the STOCEM are required to obtain acceptable confidence intervals on the outcome measures of interest for this Korea scenario?

c. Are the results of the STOCEM using deterministic assessment of attrition the same as the results of the STOCEM using stochastic assessment of attrition?

2-7. REPORT ORGANIZATION

a. Chapter 3 describes in detail the methodology employed in this research.

b. Chapter 4 reports the techniques used to update the STOCEM, to refine its representation of stochastic processes, and to treat additional processes as stochastic.

c. Chapter 5 presents the quantitative analysis of the STOCEM results, comparing deterministic with stochastic results and estimating the number of STOCEM replications required.

d. Chapter 6 provides the results of the STOCEM using deterministic assessment of combat attrition, that is, an average combat sample. These results are compared with results of STOCEM using stochastic attrition assessment, that is, random selection from the individual replications of the COSAGE, and are also compared with deterministic CEM results.

e. Chapter 7 summarizes the findings of this research and makes some recommendations concerning the application of the STOCEM.

CHAPTER 3

METHODOLOGY

3-1. OVERVIEW OF METHODOLOGY. Figure 3-1 depicts in schematic form the methodology employed in this research.

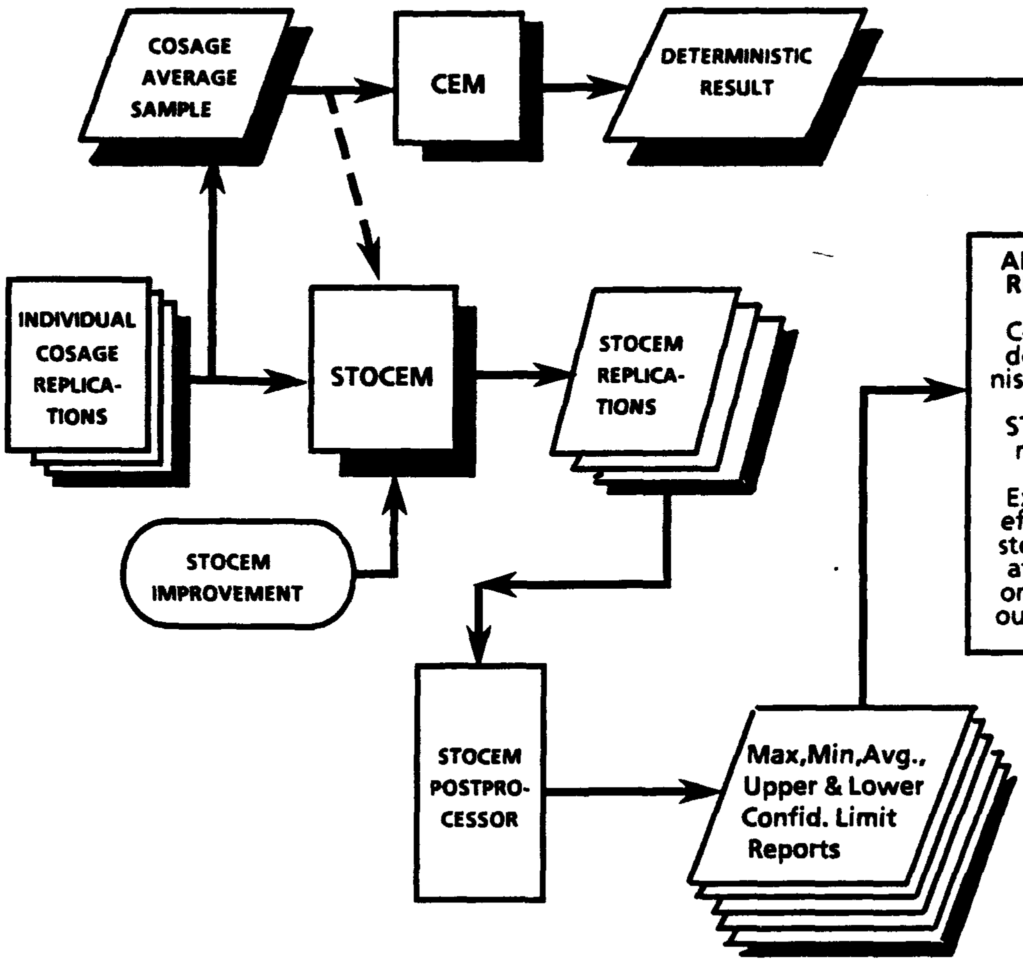

Figure 3-1. Research Methodology

3-2. TASKS

a. Our methodology begins with the improvement of the STOCEM, which is described in Chapter 4, below. We updated the STOCEM with all the improvements that exist in the latest version of the CEM; we incorporated refinements to the representation of stochastic processes, as recommended by the previous phase of analysis of STOCEM; and we added the option of stochastic treatment of the rate of displacement of the FEBA.

b. At the same time, we obtained a full set of input data for a 1992 winter campaign on the Korean peninsula. These input data include the average combat sample for each posture required by the CEM, as well as the individual replications of the COSAGE that were averaged for this combat sample. We increased the authorized loads of ammunition for maneuver and artillery units, so that ammunition would not be rationed unnecessarily, and then executed the CEM and obtained the deterministic outcome.

c. Then, using the enhanced STOCEM with all available processes in the stochastic mode and the same input data for the Korean campaign, we executed 12 replications of the STOCEM. For these STOCEM simulations, to make the STOCEM inputs as consistent as possible with those of the CEM, the mean value of the distribution of each of the stochastic processes of the STOCEM was set to the input value that was used in the CEM. The standard deviation was arbitrarily set by input at 1/10 of that mean value for the decision processes.

d. The results of the STOCEM replications are compared with the result of the base case by means of the following four different types of graphic displays of the selected outcome measures (measures of effectiveness (MOE)):

(1) Plots of all 12 values of an outcome measure for each 4-day cycle obtained from the STOCEM replications;

(2) Boxplots, showing the median, quartiles, and extreme values of the 12 replications of a STOCEM outcome measure for each 4-day cycle;

(3) Plots of the maximum and minimum values of the 12 replications of a STOCEM outcome measure for each 4-day cycle;

(4) Plots of the 90 percent confidence intervals and 95 percent confidence intervals on the mean, based on Student's t-variable (Ref 6, p 193) and on the 12 values of an outcome measure for each 4-day cycle, as follows

$$\text{Confidence limit} = X \pm t_{(1-\alpha/2,\,11)}\ s / \sqrt{12}$$

where:

$t_{(1-\alpha/2,\,11)}$	= the Student's t-variable for 11 degrees of freedom and confidence level α, where $\alpha = 0.9$ or 0.95
X	= the sample mean;
s	= the sample standard deviation:

$$s^2 = \Sigma(X_i - X)^2 / 11.$$

e. Twelve replications of the STOCEM were executed, using the same input data as in paragraph 3-2c above, with all available processes in the stochastic mode except the assessment of combat attrition, where average combat samples were used.

f. Selected STOCEM results of these simulations with deterministic attrition are compared with the results of the STOCEM made with stochastic assessment of combat attrition. Kolmogorov-Smirnov tests are used to test whether distributions of results are the same.

3-3. OUTCOME MEASURES. The outcome measures (MOE) used in our analysis were chosen as typical of the results of the CEM that are most widely used and have the greatest influence on the findings and recommendations of recent CAA studies. The selected MOE include measures of FEBA movement, attrition, and resource expenditures. For this study, the following specific outcome measures, available at 4-day intervals, are included in the analysis.

a. Cumulative (theater-wide average) displacement (kilometers (km)) of the FEBA.

b. Cumulative Blue (US and Republic of Korea (ROK)) personnel permanent casualties (dead, captured, missing, or evacuated from theater).

c. Cumulative Red (north Korean) personnel permanent casualties.

d. Cumulative Blue tanks destroyed (not repairable).

e. Cumulative Red tanks destroyed.

f. Cumulative Blue artillery weapons destroyed.

g. Cumulative Red artillery weapons destroyed.

h. Cumulative Blue ammunition consumed (tons).

i. Cumulative Red ammunition consumed (tons).

j. Red/Blue loss exchange ratio of major weapons lost during a 4-day period.

CHAPTER 4

ENHANCEMENTS TO THE STOCEM

4-1. INTRODUCTION. Several revisions of the STOCEM and enhancements to its stochastic processes were completed prior to the generation of STOCEM replications and the subsequent analysis of results.

4-2. UPDATE WITH CEM IMPROVEMENTS. The recent enhancements of the CEM were incorporated into the STOCEM code to make the STOCEM completely consistent with the latest version of the CEM, which was used to execute the base case simulation.

a. The STOCEM was modified to accept and use special combat samples for assessing attrition in engagements along the demilitarized zone (DMZ) in Korea. The DMZ combat samples are used only for engagements where a Red division is attacking against ROK maneuver forces in the prepared defense posture at the DMZ.

b. The STOCEM was updated with the CEM improvement that allows a user to specify by input the variations of weather over the course of the simulation. The weather affects the number of sorties flown by the tactical aircraft in the simulation.

c. The CEM Phased Offline Attrition (POLA), which permits a user to specify particular levels of attrition, caused by weapons or effects not modeled in the CEM, against particular segments of the forces played in the CEM at specified simulation times, was incorporated into the STOCEM.

4-3. STOCHASTIC PROCESSES WITHIN THE STOCEM

a. **Beta Distributions.** The enhancements to the STOCEM include the substitution of beta distributions for the normal distributions used in the previous version of the STOCEM in the stochastic process of determining whether a defending maneuver unit is in hasty or prepared defense. There are two reasons for changing the stochastic representation of the hasty/prepared defense decision process from a normal to a beta distribution:

(1) First, the normal distribution is unable to model adequately the hasty/prepared defense thresholds, which are restricted to nonnegative values. Since all FEBA displacement threshold levels in the CEM and STOCEM must be nonnegative, any stochastically generated negative numbers cannot be used. Whether the negative numbers drawn from a normal distribution are set to zero or discarded, the resulting distribution is distorted. For example, a comparison of Figures 4-1 and 4-2 shows the consequence of setting negative values to zero. These illustrative histograms are generated by 1,500 random draws from the normal distribution of the IMSL library programs used in the STOCEM. In Figure 4-2, any negative values are converted to zero, resulting in a noticeable "spike" in the histogram at the value zero. On the other hand, discarding negative values and making another draw until a nonnegative number is drawn has the undesirable effect of shifting the mean of the resulting distribution to a number larger than 2.0. The range of the beta distribution is a finite interval, which can be selected to include only nonnegative values.

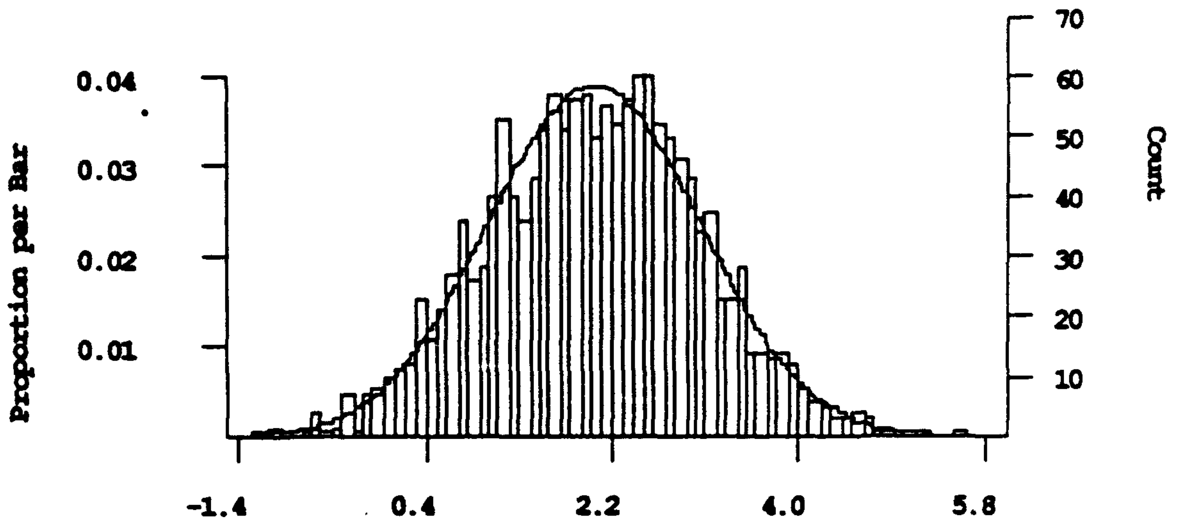

Figure 4-1. Normal Distribution with Mean = 2.0, S.D. = 1.0

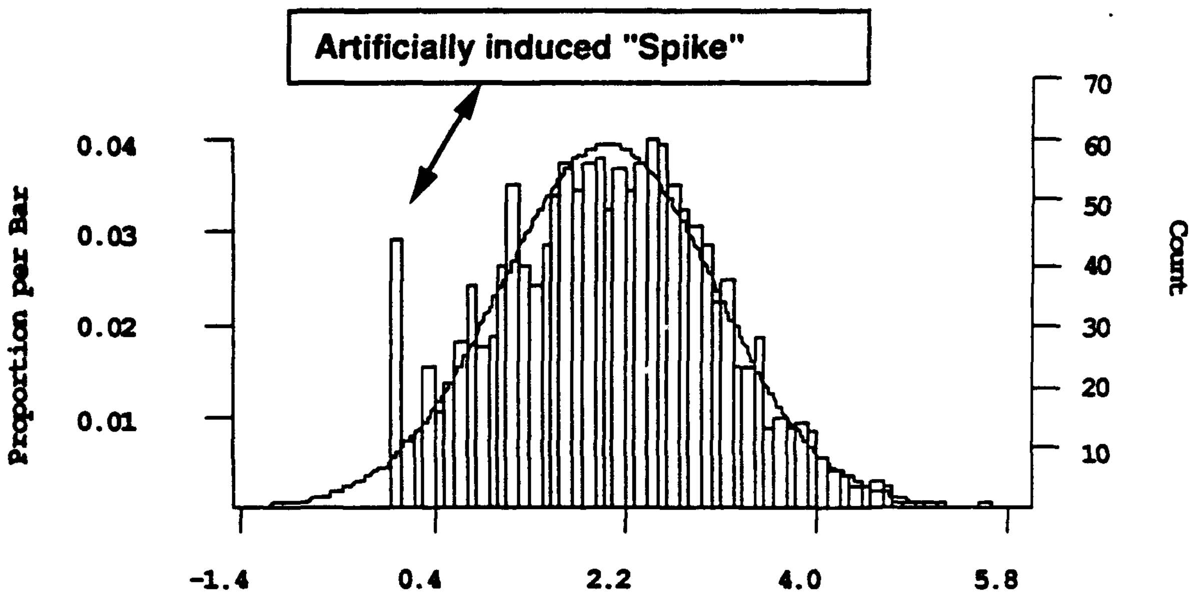

Figure 4-2. Normal Distribution with Negative Values Set to Zero

(2) Secondly, the normal distribution is symmetric about the mean, while the beta distribution affords the opportunity to select a symmetric distribution or a distribution skewed in either direction, by selecting the two parameters of the beta distribution. The beta distribution is given as follows:

$$f(y) = \begin{cases} \dfrac{y^{\alpha-1}(1-y)^{\beta-1}}{B(\alpha,\beta)}, \alpha,\beta > 0; 0 \le y \le 1 \\ 0 \textit{ elsewhere} \end{cases} \quad (1)$$

$$\textit{Where } B(\alpha,\beta) = \int_0^1 y^{\alpha-1}(1-y)^{\beta-1}\,dy$$

(3) When $\alpha = \beta$ the beta distribution is symmetric and can closely approximate the normal distribution. Larger α and β give a smaller variance, that is, a narrow and highly peaked beta distribution. The specific equation used for the hasty/prepared defense decision process in the revised STOCEM, which produces a symmetric distribution with mean = T between 0 and 2T, is as follows:

$$T' = 2.0 \times T \times RNBETA(K,K) \quad (2)$$

where:

T' = the stochastically determined decision threshold level

T = the deterministic value used as the distribution mean

K = the alpha parameter that controls the variance of the beta distribution:

$$Variance(T') = T^2/(2K+1)$$

RNBETA is the IMSL random beta *distribution*

(4) Figure 4-3 shows the shape of three examples of symmetric beta distributions ($\alpha = \beta = 4, 10, 20$) on the interval (0,1), clearly illustrating how similar the symmetric beta distribution can be to a normal distribution. The above expression for the variance of the symmetric beta distribution (with $K = \alpha = \beta$) on an interval of length 2T is derived as follows:

$$\begin{aligned} \text{Variance}(T') &= (2T)^2\alpha\beta / [(\alpha+\beta+1)(\alpha+\beta)^2] \\ &= 4T^2K^2/[(2K+1)(2K)^2] \\ &= T^2/(2K+1) \end{aligned}$$

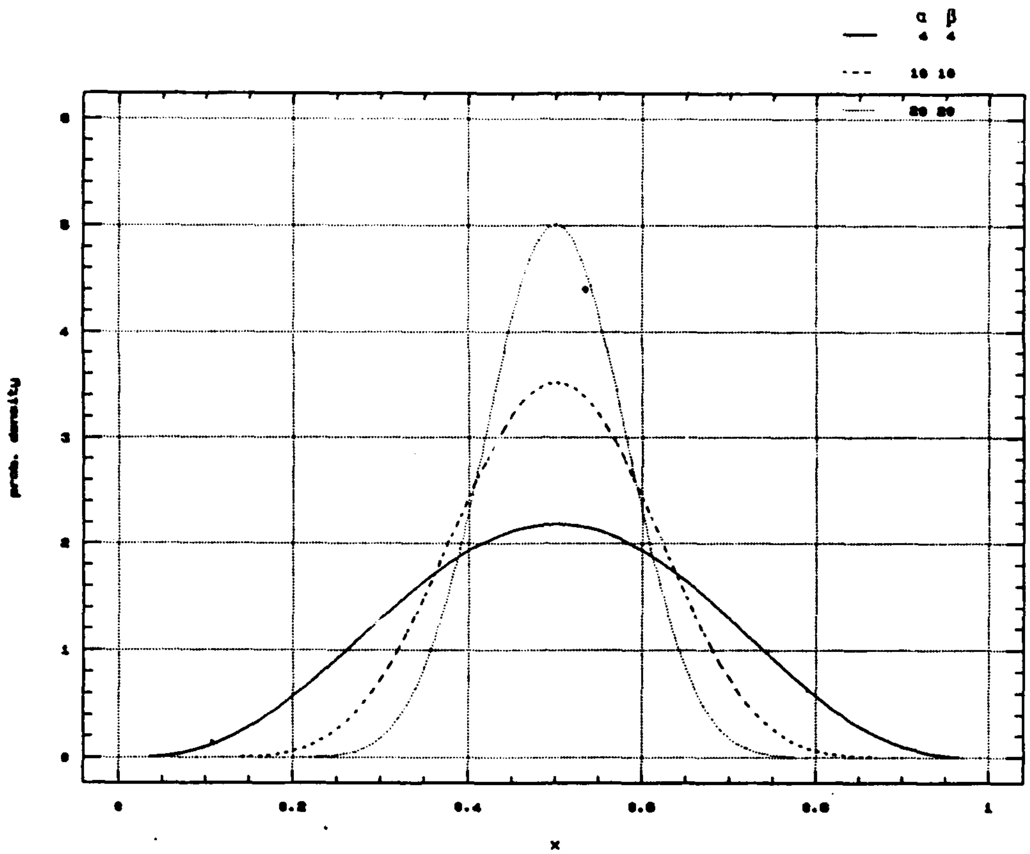

Figure 4-3. Probability Density of Selected Symmetric Beta Distributions

b. Binomial Distributions. The disposition of combat-damaged vehicles--tanks, light armor, helicopters, and artillery--is treated stochastically as a binomial distribution. A random draw is generated from a uniform distribution U(0,1). The randomly drawn number, R, is then compared to the input probability, P, of permanent loss, "K-kill," given combat damage. If R is greater than P, the vehicles damaged are classified as repairable; otherwise, they are catastrophically destroyed. The previous version of the STOCEM made the disposition decision--repairable versus destroyed--once for all the vehicles of the same type that are hit by the same shooter category in a particular engagement. That is, the disposition of more than one vehicle could be decided by a single draw from the uniform distribution, as illustrated by Figure 4-4. The same technique is applied to determine stochastically whether repairable damaged vehicles are recovered or abandoned because of an advancing enemy, except that the probability, P, of abandonment depends on the rate of FEBA displacement. In the current phase of the STOCEM research, the STOCEM was revised to dispose of one damaged vehicle (or fraction of a vehicle) at a time, using a separate random draw from the uniform distribution for each individual vehicle, or fraction thereof.

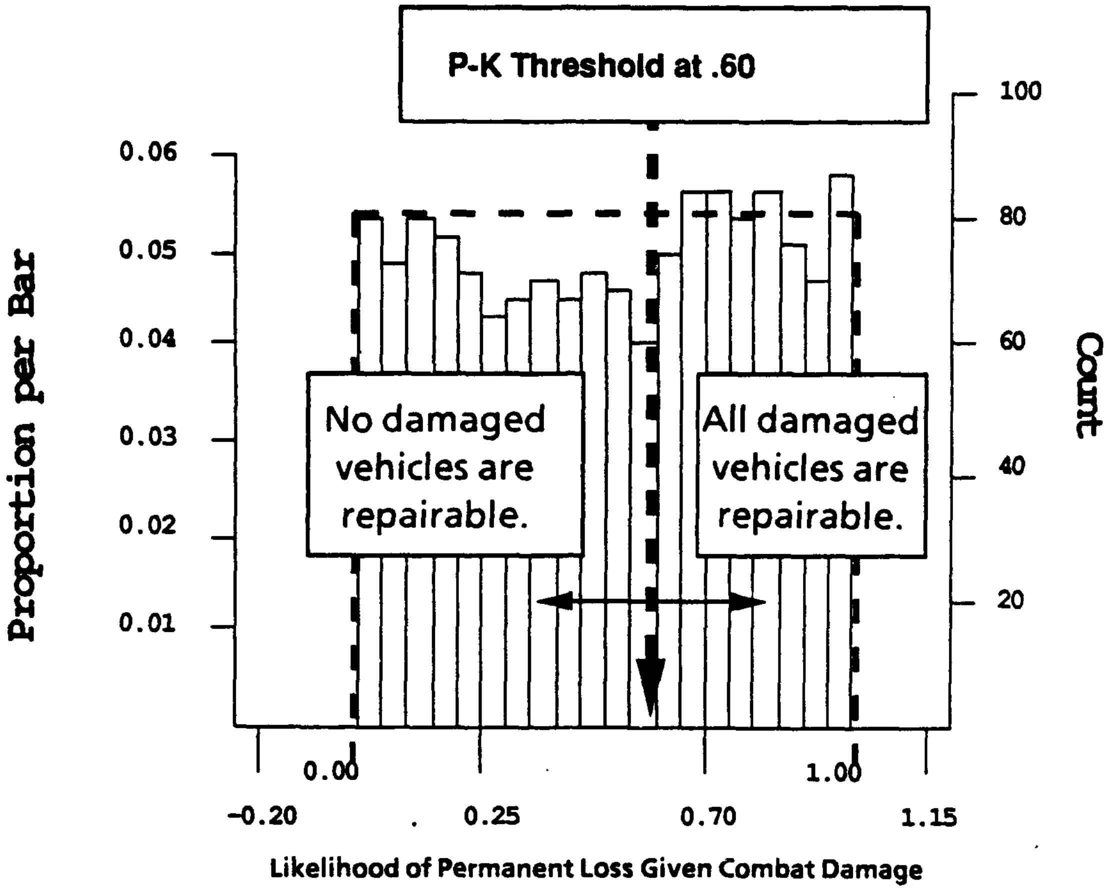

Figure 4-4. Determining the Outcome of Damage to Vehicles and Crew in STOCEM

c. **FEBA Movement.** The present research effort modified the STOCEM to provide users the option of stochastic modeling of displacement of the FEBA. The previous version of STOCEM did not treat stochastically the rate of FEBA displacement in a subsector engagement.

(1) In the deterministic mode, the attacker's rate of advance in an engagement is calculated by interpolation on an input table based on terrain type, posture, and a factor called Defender's Advantage that is derived from the fractional exchange ratio in the engagement (Reference 7, p 1-160) as follows:

$$DA = 0.5\, log_e \{[1 - (A_r / A_i)2] / [1 - D_r / D_i)2]\}$$

where A_r = attacker's combat worth remaining after the engagement,
A_i = attacker's combat worth at the start of the engagement,
D_r = defender's combat worth remaining after the engagement,
D_i = defender's combat worth at the start of the engagement.

(2) In the stochastic mode, a cumulative frequency function F for the five movement rate class intervals (very fast: > = 26 km/day, fast: 13 to 26 km/day, moderate: 5 to 13 km/day, slow: 1 to 5 km/day, and very slow: <1 km/day, for STOCEM terrain type B) is constructed as a function of terrain type, posture and Defender's Advantage, using the findings of R. Helmbold (Reference 8). For a particular engagement, the Defender's Advantage is calculated and a random number R is drawn from the uniform distribution U(0, 1). The inverse of F, $F^{-1}(R)$, yields a movement rate class, and the outcome movement rate is randomly selected using a uniform distribution within the boundaries of the selected movement rate class interval. Figure 4-5 depicts how the probabilities of the five movement rate classes are related to the value of Defender's Advantage for the engagement, derived from historical battles. In Figure 4-5, the movement rate classes for a given value of Defender's Advantage have the probabilities shown by the vertical distances between the curves above that value.

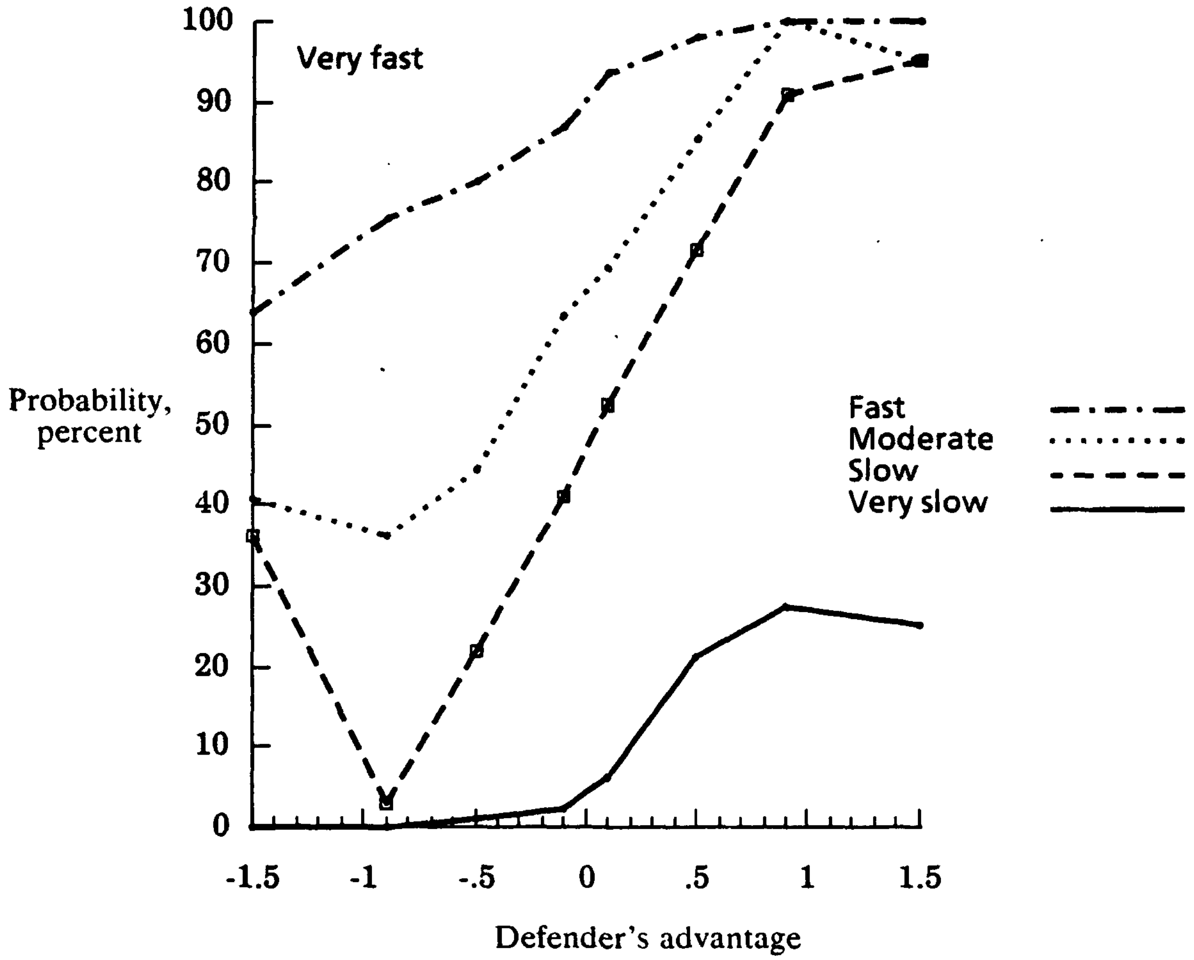

Figure 4-5. Rate of Advance versus Defender's Advantage

CHAPTER 5

ANALYSIS OF STOCEM RESULTS

5-1. INTRODUCTION. The analysis of this study, using simulations of a current Korea campaign, is designed to:

a. Compare the deterministic CEM result with the Stochastic CEM results.

b. Estimate the number of replications of the STOCEM required to obtain satisfactory confidence intervals on the selected outcome measures.

5-2. SCENARIO

a. This research effort utilized a current Korea scenario for the purpose of: (1) verifying and demonstrating the recent enhaneements of the STOCEM; (2) illustrating the feasibility and potential benefits of employing STOCEM as an analysis tool in future studies; and (3) estimating the number of replications of the STOCEM required to obtain satisfactory confidence intervals on the selected outcome measures.

b. The general concept of the scenario used in this study involves the attack southward across the DMZ by north Korean forces along a north to south invasion route. The opposing forces are comprised of US and allied ROK combat units, which will counterattack northward if their strength permits. Adjustments were made to ammunition inputs, so that these simulations do not agree exactly with those used in other CAA analyses.

5-3. STOCHASTIC VERSUS DETERMINISTIC RESULTS

a. A deterministic simulation of a realistic 1992 Korea campaign was executed using the CEM. Twelve replications of the STOCEM were executed with all available processes in the stochastic mode, using the same input data as in the CEM simulation. STOCEM results for the outcome measures listed in paragraph 3-3, Chapter 3, are compared with the CEM result, using a variety of graphic displays, as illustrated by the figures of this chapter.

b. Figure 5-1 shows all of the 12 STOCEM replication outcome values for every 4-day period as small circles centered on the ending day of the 4-day period, with the deterministic CEM outcc · shown as a line.

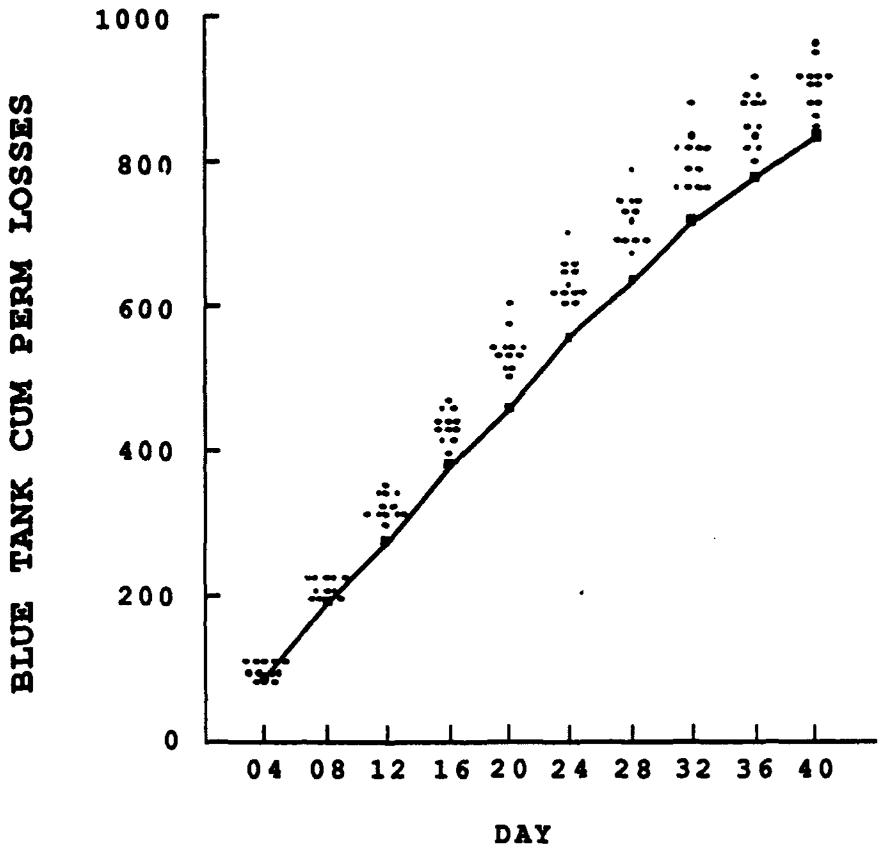

Figure 5-1. STOCEM Outcome Values vs CEM Result, Cumulative Blue Tanks Destroyed

c. Figure 5-2 is an example of the use of boxplots to display the distribution of the STOCEM results. A boxplot of the STOCEM outcomes is shown for every 4-day period of the simulation, with the deterministic CEM outcome shown as a line. The boxplot conventions are that the line across the box shows the median; the upper and lower limits of the box are the quartiles; the upper whisker is drawn to the largest value below U, the upper quartile plus 1.5 times the interquartile range; and the lower whisker is drawn to the smallest value greater than L, the lower quartile minus 1.5 times the interquartile range. Boxplot displays, like Figure 5-2, for all 10 STOCEM outcome measures are provided in Appendix C.

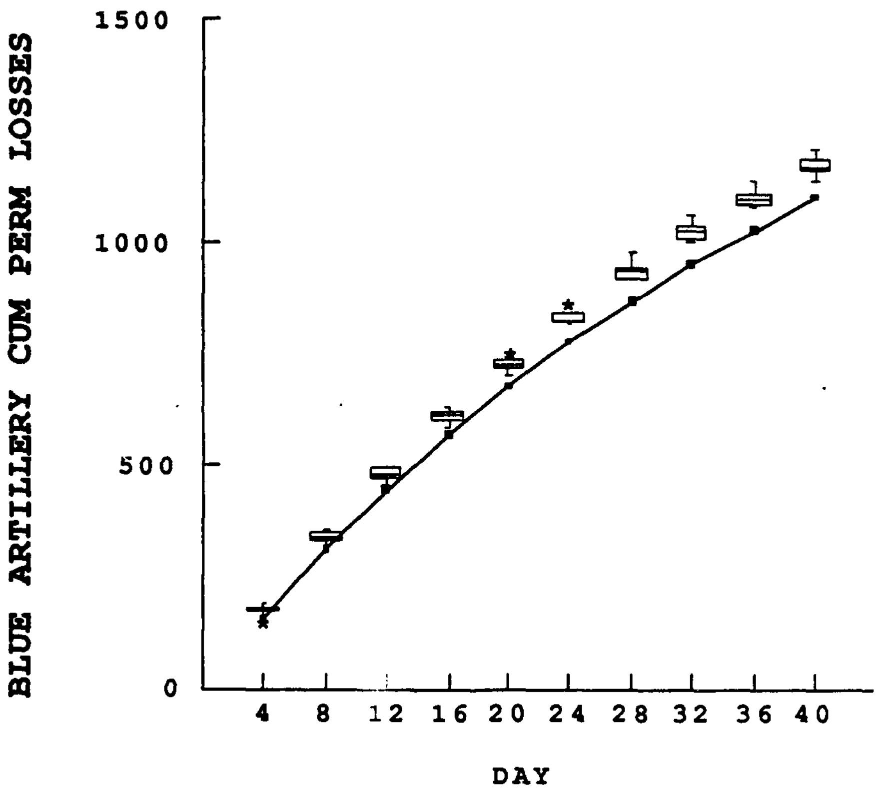

Figure 5-2. STOCEM Outcome Boxplots vs CEM Result, Cumulative Blue Artillery Destroyed

d. Figure 5-3 shows, as dashed lines, the maximum and minimum of the 12 STOCEM outcome values, compared to the CEM result, which is shown as the solid line.

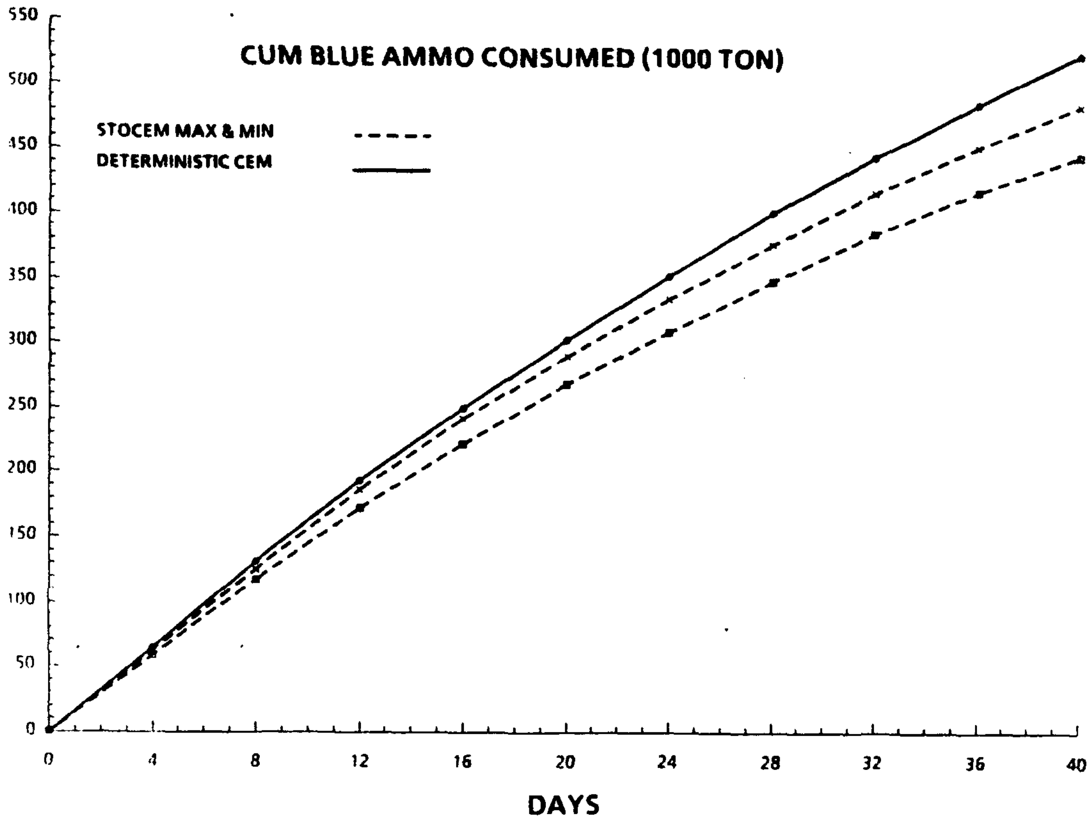

Figure 5-3. STOCEM Outcome Range vs CEM Result. Cumulative Blue Ammunition Consumed

e. Figure 5-4 shows, on the left, as shaded areas, the best, mean and worst cumulative terrain loss of the STOCEM replications in each sector, at simulation day 32. On the right, the cumulative terrain loss by day 32 of the CEM base case is shaded. The deterministic CEM results lie between the STOCEM minimum and maximum Red advances in the central sectors; but in the western and eastern coastal sectors of Korea, Blue forces were more successful in regaining terrain in the CEM base case than in any STOCEM replication.

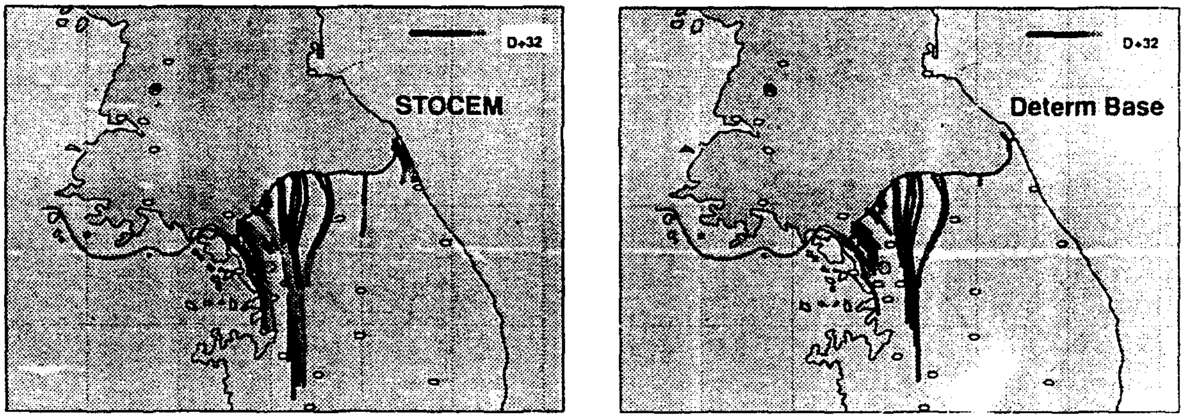

Figure 5-4. Day 32: STOCEM Minimum, Mean, and Maximum Cumulative Terrain Loss by Sector (left) vs CEM Base Case

f. Figure 5-5 shows, as dashed lines, the 90 percent confidence interval of the STOCEM results, compared with the deterministic CEM result, which is shown as the solid line. Confidence interval displays, like Figure 5-5, for all 10 STOCEM outcome measures, are provided in Appendix C.

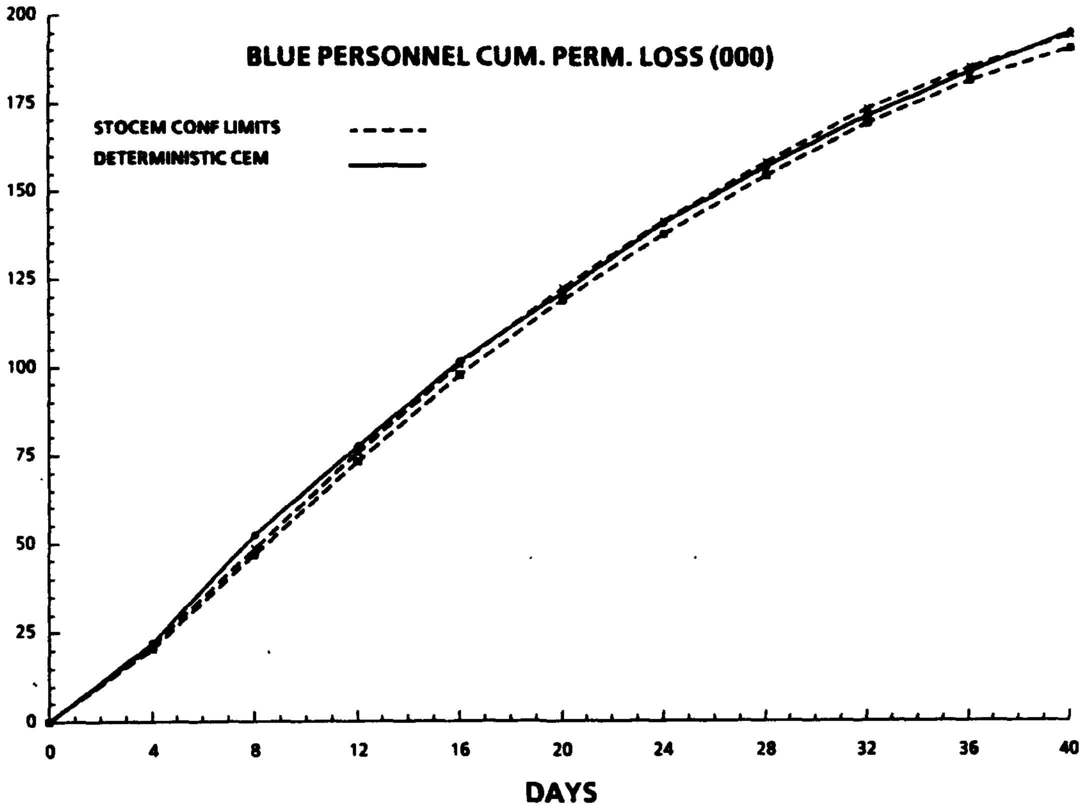

Figure 5-5. STOCEM Outcome 90 Percent Confidence Limits vs CEM Result, Cumulative Permanent Losses of Blue Personnel

g. An examination of these graphics revealed that the CEM result would be an outlier of the distribution of STOCEM results for all outcome measures except Blue personnel losses and Red tanks destroyed. These findings are different from the observations of the analysis of STOCEM in the Iraq scenario (Ref.5), but similar to the findings of the first analysis of STOCEM (Ref. 4). There are differences between Ref. 5 and the analysis reported here that may contribute to the closer agreement in Ref. 5 between deterministic and STOCEM results, including the following.

(1) First, the stochastic representation of the FEBA displacement process in the latest STOCEM was not available in the STOCEM version used in Ref. 5; so the stochastic FEBA displacement process in the current STOCEM is a new potential source of difference from the CEM.

(2) Finally, the present analysis compares the deterministic CEM results with 12 STOCEM replications. The 11 cases of Ref. 5 with 5 STOCEM replications per case provide a larger sample (55) and hence a better basis for comparison with the deterministic results.

h. This finding has prompted further analysis, to gain a better understanding of the discrepancy between the CEM result and the distribution of STOCEM results. The attrition calculation, ATCAL, was executed for a subsector engagement that occurred in the first day of the CEM simulation. ATCAL was executed first using the combat sample used in the deterministic CEM simulation, that is, an average of the five replications of COSAGE. Then ATCAL was executed five times using as combat sample each of the individual replications of COSAGE. The results of ATCAL, rounds fired by each weapon type and combat losses of each weapon type, are shown in Table 5-1, where "Shots 1" indicates the shots fired of the first munition type of an asset that fires two munition types and "Shots 2" indicates the shots fired of the second munition type. An examination of these results yields the following observations.

(1) In general, the results (attrition and rounds fired by weapon type) of ATCAL using the average combat sample are not identical to the mean of the results of the five ATCAL assessments using the individual replications of COSAGE.

(2) For every ATCAL outcome measure (attrition and rounds fired by weapon type), the result of ATCAL using the average combat sample is within the range of the results of the five ATCAL assessments using the individual replications of COSAGE.

5-4. STOCEM REPLICATIONS REQUIRED

a. We estimate the number of STOCEM replications required to obtain 90 percent confidence intervals less than 1/10 of the mean of the above MOE by increasing the quantity N of replications until the following inequality is satisfied (Ref. 6, p 193):

$$t_{(0.05, N-1)}\, s / \sqrt{N} < 0.05 X$$

where

$t_{(0.05, N-1)}$ denotes the Student t-variable for N-1 degrees of freedom,
X denotes the sample mean,
s denotes the sample standard deviation:

$$s^2 = \Sigma(X_i - X)^2/(N-1)$$

Table 5-1. Losses and Shots Fired in ATCAL Engagement

Asset ID /MOE	Average Sample	Replication 1	Replication 2	Replication 3	Replication 4	Replication 5
3 / Losses	1.15	0.71	1.73	2.22	0.78	1.30
33 / Losses	5.98	5.04	7.21	7.26	3.76	6.32
35 / Losses	0.54	0	1.22	0	0.48	1.70
36 / Losses	0.63	0.50	0.74	0.98	0.44	0.72
37 / Losses	0.22	0	0.96	0.24	0.17	0.18
42 / Losses	74.23	60.49	88.54	86.42	38.79	94.86
49 / Losses	2.23	1.40	1.81	2.47	2.80	2.67
50 / Losses	0.51	0	0.37	0.71	0.42	0.70
53 / Losses	1.76	1.79	2.64	1.98	0.87	1.74
69 / Losses	0.06	0	0.05	0.02	0.06	0.13
70 / Losses	0.03	0	0.08	0.01	0.04	0.02
83 / Losses	0.32	0.17	0.17	0.29	0.51	0.25
85 / Losses	1.22	1.50	1.64	0.86	0.67	1.29
93 / Losses	164.2	179.8	192.4	164.9	119.1	168.8
94 / Losses	1.03	1.38	1.32	0.49	0.88	0.78
95 / Losses	5.72	5.29	6.93	5.98	4.82	4.66
98 / Losses	2.49	2.37	3.38	1.74	2.62	1.59
101 / Losses	0.04	0.07	0.01	0.01	0.07	0.02
3 / Shots 1	3.69	3.41	6.63	2.73	1.93	4.44
3 / Shots 2	181.7	171.5	139.6	256.5	102.0	231.8
33 / Shots	89.2	73.7	84.5	81.7	63.4	115.5
36 / Shots	0.11	0.06	0.40	0.02	0	0.14
37 / Shots	315.5	360.5	797.9	463.1	102.8	324.9
42 / Shots 1	191.7	162.1	251.9	134.4	76.3	347.1
42 / Shots 2	1194.	1182.	1817.	1113.	808.	1129.
49 / Shots 1	366.3	392.4	378.3	343.5	427.8	319.2
49 / Shots 2	238.7	274.9	263.2	240.4	133.0	248.5
50 / Shots	375.1	283.2	320.3	536.5	336.2	329.5
53 / Shots	6.02	7.09	8.42	4.86	2.24	7.89
83 / Shots	735.7	641.6	858.6	1051.2	338.3	769.0
85 / Shots	1.68	2.68	0.77	1.13	2.03	1.55
93 / Shots	158.2	120.8	195.1	191.7	113.4	177.8
94 / Shots	301.9	279.8	291.3	206.6	318.1	322.8
95 / Shots	1476.	984.	2185.	1592.	855.	1706.
98 / Shots	1104.	669.	1778.	1076.	468.	1406.
101 / Shots	1017.	877.	771.	917.	1093.	1048.

b. As an illustration, Table 5-2 shows how the width of the confidence interval varies with the desired level of confidence and the number of STOCEM replications, for one particular outcome measure, the average cumulative terrain loss at day 20, whose sample mean is 45.57 km and sample standard deviation is 3.86 km for 12 replications of STOCEM. It is recognized that these confidence intervals based on Student's t-variable are only approximate, because the STOCEM outcome measures are not necessarily distributed normally. No better estimate of confidence intervals for the mean of an unknown distribution is available, and for larger N, the Central Limit Theorem guarantees normality of the sample mean and applicability of Student's t-variable.

Table 5-2. Width of Confidence Interval, Cumulative Average Terrain Loss (km), Day 20

Replications	80% Confidence	90% Confidence	95% Confidence	99% Confidence
2	16.81	34.48	69.41	347.67
3	8.41	13.02	19.19	44.26
4	6.33	9.09	12.29	22.56
5	5.01	7.36	9.59	15.90
6	4.65	6.35	8.11	12.71
7	4.20	5.67	7.14	10.82
8	3.86	5.17	6.46	9.55
9	3.60	4.79	5.94	8.64
10	3.38	4.48	5.52	7.94
11	3.20	4.22	5.19	7.38
12	3.04	4.00	4.91	6.93

c. The results obtained, for simulation day 20 and day 40, are provided in Table 5-3. For every MOE considered, 12 replications of STOCEM are sufficient; and, except for the loss exchange ratio and the FEBA movement, which are the outcome measures that exhibit the greatest variability, five replications of STOCEM are sufficient.

Table 5-3. STOCEM Replications Required for 90 Percent Confidence Intervals < 1/10 of Mean

STOCEM outcome	Day 20	Day 40
Mean cumulative FEBA movement	10	8
Blue cum permanent personnel loss	4	3
Red cum permanent personnel loss	3	3
Blue cumulative tanks destroyed	5	5
Red cumulative tanks destroyed	3	3
Blue cumulative artillery destroyed	3	3
Red cumulative artillery destroyed	4	4
Blue cum ammunition consumption	3	3
Red cum ammunition consumption	4	4
Red/Blue weapon loss exchange ratio	12	9

d. A different criterion, 99 percent confidence intervals less than 1/5 of the mean, which implies replacing the above inequality by

$$t_{(0.005, N-1)} s / \sqrt{N} < 0.1\, X,$$

yields the required numbers of STOCEM replications shown in Table 5-4.

Table 5-4. STOCEM Replications Required for 99 Percent Confidence Intervals < 1/5 of Mean

STOCEM outcome	Day 20	Day 40
Mean cumulative FEBA movement	9	8
Blue cum permanent personnel loss	4	4
Red cum permanent personnel loss	4	3
Blue cumulative tanks destroyed	6	5
Red cumulative tanks destroyed	4	4
Blue cumulative artillery destroyed	4	4
Red cumulative artillery destroyed	4	5
Blue cum ammunition consumption	4	4
Red cum ammunition consumption	5	4
Red/Blue weapon loss exchange ratio	10	8

5-5. OBSERVATIONS

a. The deterministic CEM result would statistically be an outlier of the distribution of STOCEM results for most of the outcome measures.

b. For every MOE considered, 12 replications of STOCEM are sufficient to obtain 90 percent confidence intervals narrower than 1/10 of the mean value of the MOE. For every MOE considered, 10 replications of STOCEM are sufficient to obtain 99 percent confidence intervals narrower than 1/5 of the mean value of the MOE.

CHAPTER 6

STOCEM ASSESSMENT OF COMBAT ATTRITION

6-1. STOCHASTIC VERSUS DETERMINISTIC ASSESSMENT

a. An analysis was undertaken to examine whether the results of STOCEM with deterministic attrition are significantly different from results of STOCEM with stochastic attrition.

b. Twelve replications of the STOCEM were executed, using the same input data as in the CEM simulation, with all STOCEM processes in the stochastic mode except combat attrition, where average combat samples were used, as in the CEM, rather than randomly selected individual replications of COSAGE.

c. Kolmogorov-Smirnov (K-S) tests (Ref. 9, p 304) are applied to the distributions of the selected MOE, to test whether distributions of STOCEM results using stochastic and deterministic attrition are the same. Table 6-1 summarizes the results of these K-S tests. We reject the hypothesis that the two distributions are the same, at the 90 percent confidence level, for 15 of the 20 MOE considered. Thus it is established that stochastic and deterministic attrition in STOCEM yield significantly different STOCEM outcomes.

Table 6-1. Probability that Distributions of STOCEM Results with Stochastic and Deterministic Attrition are the Same

STOCEM outcome	Day 20	Day 40
Mean cumulative FEBA movement	.0015	.0002
Blue cum permanent personnel loss	.2558	.5361
Red cum permanent personnel loss	.0079	.0000
Blue cumulative permanent tank loss	.0000	.0002
Red cumulative permanent tank loss	.0314	.9985
Blue cum permanent artillery loss	.0000	.0000
Red cum permanent artillery loss	.0002	.0000
Blue cum ammunition consumption	.0000	.0000
Red cum ammunition consumption	.2558	.5361
Red/Blue weapon loss exchange ratio	.0002	.0314

d. Furthermore, we can establish that these distributions differ statistically significantly in central tendency (mean) rather than merely in spread (variance), by observing that the 90 percent confidence intervals of the distributions of STOCEM results with stochastic and deterministic attrition frequently do not overlap, as can be seen, for example, in Figure 6-1. A set of comparative confidence interval displays for all 10 selected MOE is provided at Appendix D.

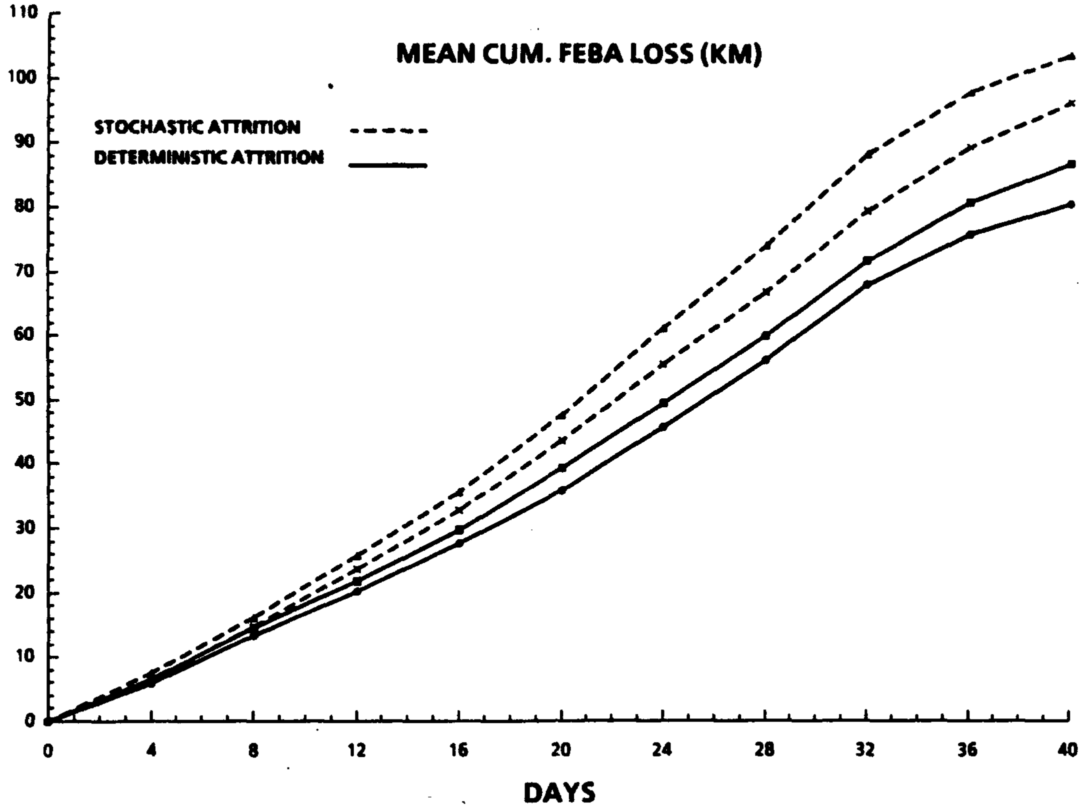

Figure 6-1. 90 Percent Confidence Limits, STOCEM with Stochastic vs STOCEM with Deterministic Attrition, Mean Cumulative Terrain Loss (km)

e. These findings differ somewhat from the previous phase of analysis of STOCEM (Ref. 5), which found that stochastic assessment of combat attrition was a principal cause of variability in only a few of the STOCEM outcome measures in the simulations of an Iraq scenario. These findings are not necessarily inconsistent, for it is possible that a similar experimental design for STOCEM simulations of this Korea campaign could reveal other stochastic processes of the STOCEM that produce greater variability in certain outcome measures than does the stochastic assessment of combat attrition.

6-2. COMPARISON WITH CEM

a. Figure 6-2 shows, on the left, as shaded areas, the best, mean, and worst cumulative terrain loss of the of the STOCEM replications in each sector, at simulation day 32. On the right, the cumulative terrain loss by day 32 of the CEM simulation is shaded. The deterministic CEM results lie between the STOCEM minimum and maximum terrain loss in all but the eastern sectors of Korea, where Blue forces were more successful in regaining terrain in the CEM simulation than in any STOCEM replication. A comparison of Figures 6-2 and 5-4 shows that the CEM day 32 location of the FEBA is more consistent with the STOCEM results using deterministic assessment of combat attrition than with STOCEM using stochastic attrition assessment.

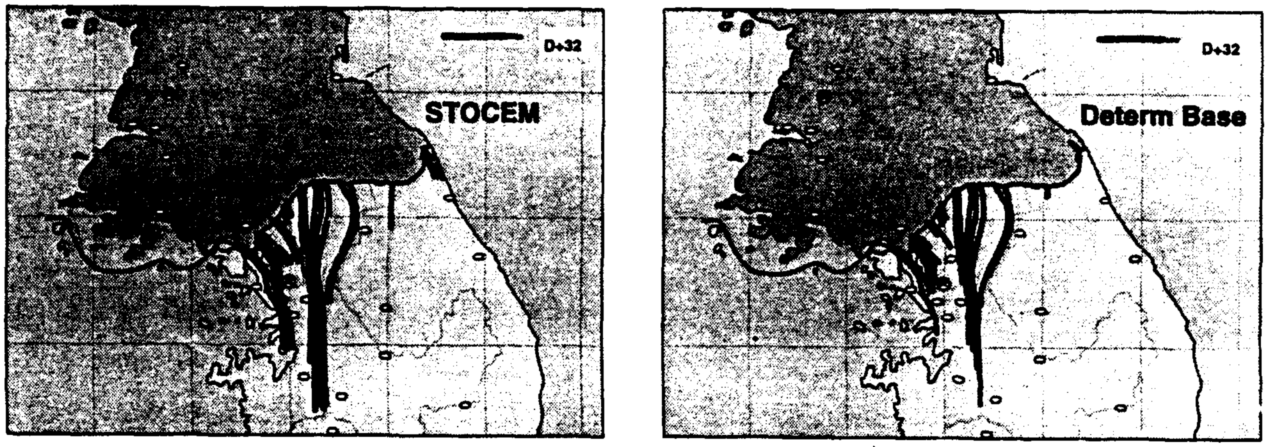

Figure 6-2. Day 32, Deterministic Attrition: STOCEM Minimum, Mean and Maximum Cumulative Terrain Loss by Sector (left) vs CEM Base Case

b. From graphics such as Figure 6-3, we determine that the deterministic CEM result falls within the 90 percent confidence limits of the distribution of results of STOCEM with deterministic attrition for most of the MOE. A set of confidence interval displays for all 10 selected MOE is provided at Appendix D. For every MOE considered, the CEM simulation agrees better with the results of STOCEM using deterministic attrition than with STOCEM using stochastic attrition. This is not surprising, because, of course, the CEM simulation uses deterministic attrition.

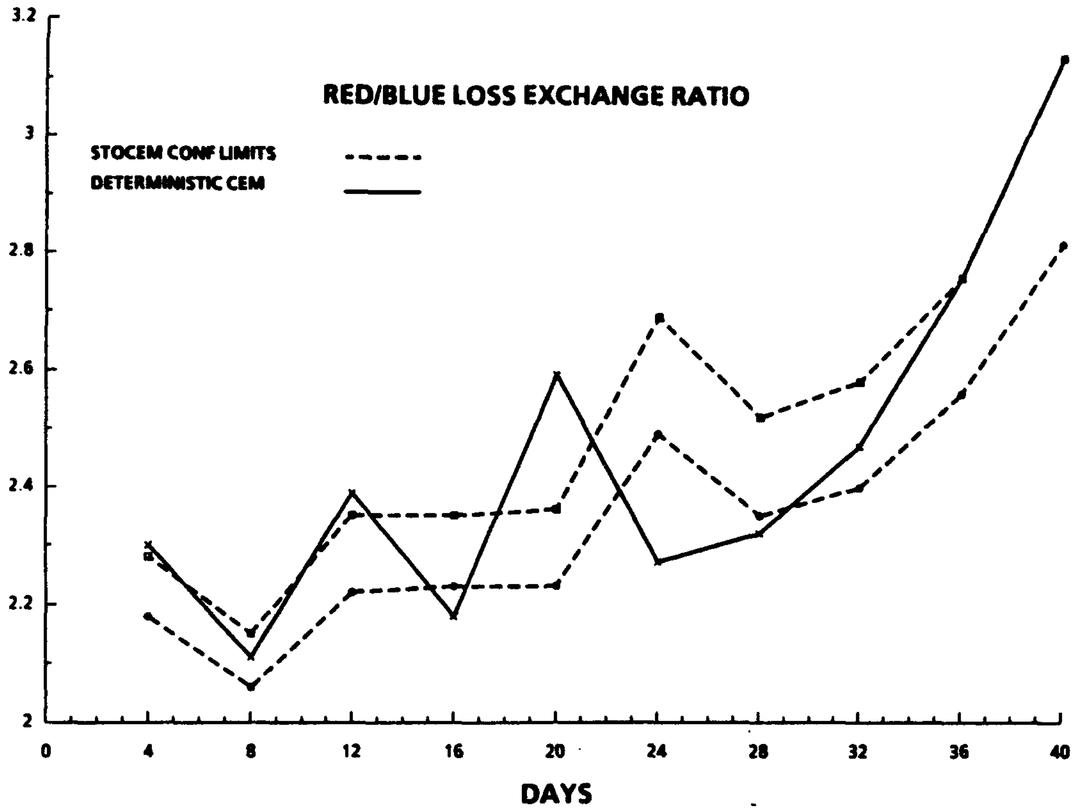

Figure 6-3. STOCEM with Deterministic Attrition 90 Percent Confidence Limits vs CEM Result, Red/Blue Weapon Loss Exchange Ratio

c. Figure 6-4 shows the 95 percent confidence limits for the same MOE as Figure 6-3. A comparison of these figures indicates how much the confidence intervals increase between 90 percent and 95 percent confidence for this 12-replication sample.

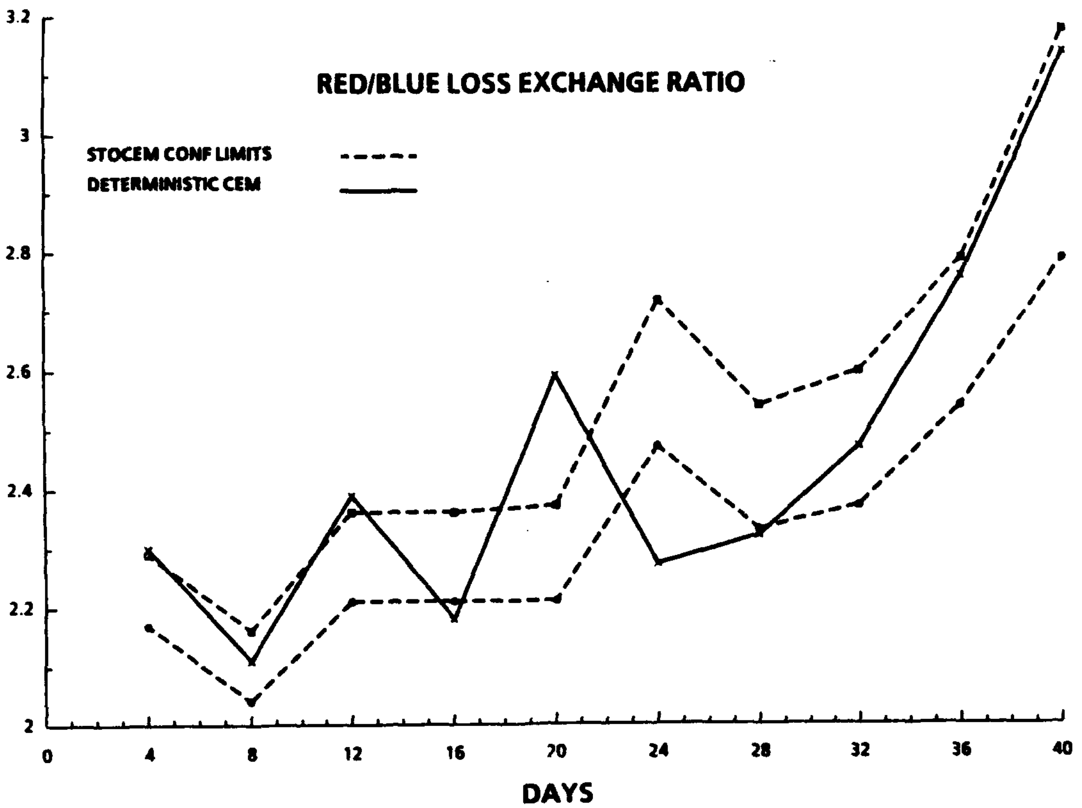

Figure 6-4. STOCEM with Deterministic Attrition 95 Percent Confidence Limits vs CEM Result, Red/Blue Weapon Loss Exchange Ratio

6-3. OBSERVATIONS

a. Stochastic and deterministic attrition in STOCEM yield statistically significantly different STOCEM outcomes.

b. The CEM result agrees better with the results of STOCEM using deterministic attrition than with STOCEM using stochastic attrition.

CHAPTER 7

SUMMARY

7-1. ESSENTIAL ELEMENTS OF ANALYSIS

a. How do the results of stochastic simulation of a Korean campaign compare with deterministic CEM results?

ANSWER: For many of the outcome measures examined, the result from the CEM is outside the 90 percent confidence interval and outside the range of the distribution of results from the STOCEM.

b. How many replications of the STOCEM are required to obtain acceptable confidence intervals on the outcome measures of interest for this Korea scenario?

ANSWER: No more than 12 replications are required for 90 percent confidence intervals no wider than 1/10 of the mean values of the outcome measures examined. No more than 10 replications are required for 99 percent confidence intervals no wider than 1/5 of the mean values of the outcome measures examined.

c. Are the results of the STOCEM using deterministic assessment of attrition the same as the results of the STOCEM using stochastic assessment of attrition?

ANSWER: No, for many of the outcome measures examined the distribution of results of the STOCEM using deterministic assessment of attrition (average combat sample) are statistically significantly different from the distribution of results of the STOCEM using stochastic assessment (individual replications of the COSAGE).

7-2. OTHER INSIGHTS

a. This research has improved the stochastic representation of processes in the STOCEM and has updated the STOCEM with the latest modifications of the CEM. Our research demonstrates the feasibility of obtaining usable results from a stochastic campaign simulation for a Korea scenario with realistic forces. The simulation results also demonstrate that a deterministic simulation using "expected-value" inputs cannot be guaranteed to produce results that are central in any sense to the distribution of possible outcomes.

b. For the outcome measures considered, the CEM result agrees better with the results of STOCEM using deterministic assessment of attrition than with STOCEM using stochastic assessment of attrition. This is not surprising, because, of course, the CEM simulation uses deterministic attrition. In fact, for most of the selected outcome measures and most of the simulation days, the hypothesis that the deterministic CEM result comes from the same distribution as the results from the STOCEM using deterministic assessment (average combat sample) could not be rejected at the 90 percent confidence level.

c. The deterministic CEM result would be an outlier of the distribution of STOCEM results for all outcome measures except Blue personnel losses and Red tanks destroyed. These findings are different from the observations of the analysis in the Iraq scenario (Ref.5), but similar to the findings of the first analysis of STOCEM (Ref. 4). There are differences between Ref. 5 and the analysis reported here that may contribute to the closer agreement in Ref. 5 between deterministic and STOCEM results, including the following.

(1) First, the stochastic representation of the FEBA displacement process in the latest STOCEM was not available in the version of the STOCEM used in Ref. 5; so the stochastic FEBA displacement process in the current STOCEM is a new potential source of difference from the CEM.

(2) Finally, the present analysis compares the deterministic CEM results with 12 STOCEM replications. The 11 cases of Ref. 5 with 5 STOCEM replications per case provide a larger sample (55) and hence a better basis for comparison with the deterministic results.

d. In general, the results (attrition and rounds fired by weapon type) of the CEM combat assessment calculation, ATCAL, using the average combat sample are not identical to the mean of the results of the ATCAL assessments using the individual replications of COSAGE. However in the cases examined, for both attrition and rounds fired by weapon type, the result of ATCAL using the average combat sample is well within the range of the results of the five ATCAL assessments using the individual replications of COSAGE.

e. Once again it should be noted that these insights are scenario-dependent and do not necessarily extend to STOCEM simulations of other campaigns.

7-3. RECOMMENDATIONS

a. Replications Required. From the analysis of the STOCEM results reported here, it is recommended that no more than 12 and no fewer than 5 replications of STOCEM are executed for any one scenario, depending on which CEM outcome measures are to be used in the analysis. Variances and confidence intervals of these outcome measures should be examined to estimate the required number of STOCEM replications.

b. Applications. It is recommended that the STOCEM be applied in future campaign analyses as the base case. By generating STOCEM replications as a base case, it can be determined statistically whether excursions and varying assumptions produce significantly different outcomes. Of course, the range and distribution of possible outcomes of the base case situation will also be a product of the STOCEM replications.

c. Further Testing

(1) CAA should conduct further analysis of the ATCAL assessment process in the STOCEM, to explain the statistically significant differences between the distributions of STOCEM results using stochastic versus deterministic assessment of combat engagements. The present work establishes that the stochastic and deterministic assessment yield different STOCEM results, but it does not explain why the results are different, nor establish which results are preferable. Testing of the STOCEM should be conducted using the Ardennes Campaign data base so that it can be determined whether stochastic or deterministic assessment yields simulation results that are more consistent with historical records.

(2) Testing should examine the effects on distributions of STOCEM results of (a) the quantity of replications of the COSAGE; (b) the quantity of replications of the STOCEM; and (c) the variance of the distributions assumed in the STOCEM decision processes.

(3) As nonmonotonic or counterintuitive results of the CEM are found, the same simulations should be executed using the STOCEM, to determine whether the use of stochastic simulation eliminates the nonmonotonic results.

APPENDIX A

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APPENDIX B

REFERENCES/BIBLIOGRAPHY

REFERENCES

1. Louer, Philip E., "More on Non-Linear Effects," Phalanx, Vol. 26, No. 1, March 1993, p. 22

2. Youngren, Mark A., "Stochastic Architecture for Theater-level Modeling," Phalanx, Vol. 24, No. 1, March 1991

3. Box, George E., Norman R. Draper, Empirical Model-Building and Response Surfaces, John Wiley & Sons, Inc., NY 1987

4. Stochastic Concepts Evaluation Model (STOCEM), CAA-TP-91-6, US Army Concepts Analysis Agency, Bethesda, MD, August 1991

5. Stochastic Concepts Evaluation Model - Phase II (STOCEM-Phase II), CAA-TP-92-2, US Army Concepts Analysis Agency, Bethesda, MD, June 1992

6. Mode, Elmer B., Elements of Statistics, 3d edition, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1961

7. Concepts Evaluation Model VII (CEM VII), Volume II - User's Handbook, CAA-D-85-1, US Army Concepts Analysis Agency, Bethesda, MD, December 1991

8. Rates of Advance in Historical Land Combat Operations, CAA-RP-90-1, US Army Concepts Analysis Agency, Bethesda, MD, June 1990

9. Conover, W. J., Practical Nonparametric Statistics, John Wiley & "Sons, Inc., New York, 1971

BIBLIOGRAPHY

Concepts Evaluation Model VI (CEM VI), Volume I - Technical Description, October 1987, US Army Concepts Analysis Agency, Bethesda MD

IMSL User's Manual STAT/LIBRARY, Vol. 3, IMSL Inc., 1987

APPENDIX C

COMPARISON OF STOCEM WITH DETERMINISTIC CEM RESULTS

C-1. DESCRIPTION OF FIGURES. This appendix contains 20 figures that graphically compare the results of the deterministic CEM baseline with the distribution of 12 STOCEM replications with all available STOCEM processes, including the assessment of combat attrition, operating in the stochastic mode. Figures C-1 to C-10 depict, as boxplots, the 10 selected outcome measures at 4-day intervals of the simulation, overlaid by a line representing the deterministic CEM result. Figures C-11 to C-20 show the 90 per cent confidence intervals of the 10 selected outcome measures as a function of simulation time, overlaid by a line representing the deterministic CEM result. All the MOE except loss exchange ratio (Figures C-10 and C-20) are cumulative from the simulation start, rather than the results of a single cycle. For example, Figure C-1 shows the cumulative terrain lost per minisector by Blue, averaged across the theater. In all the figures of Appendix C the deterministic result is shown by a solid line. The 12 STOCEM replications in Figures C-1 to C-10 are shown by box plots--one for every 4-day period--with the following conventions.

a. The lower edge of each box depicts the value of the lower quartile of the STOCEM replications--halfway between the third and fourth replications, in order of magnitude, of the particular outcome measure.

b. The upper edge of each box depicts the value of the upper quartile of the STOCEM replications--halfway between the ninth and tenth replications, in order of magnitude, of the particular outcome measure.

c. The line across each box depicts the median of the STOCEM replications--halfway between the sixth and seventh replications, in order of magnitude, of the particular outcome measure. If the median line is not visible, it must coincide with either the lower quartile or upper quartile.

d. The lower "whisker" depicts the smallest value of the 12 STOCEM replications that falls within 1.5 times the interquartile range (IQR, which is the height of the box), from the lower quartile.

e. The upper "whisker" depicts the largest value of the 12 STOCEM replications that falls within 1.5 times the IQR from the upper quartile.

f. If the result of any STOCEM replication falls beyond 1.5 times the IQR, but within 3.0 times the IQR, from the nearer quartile, then this value is depicted by a disconnected asterisk.

g. If the result of any STOCEM replication falls beyond 3.0 times the IQR from the nearer quartile, then this value is depicted by a disconnected circle.

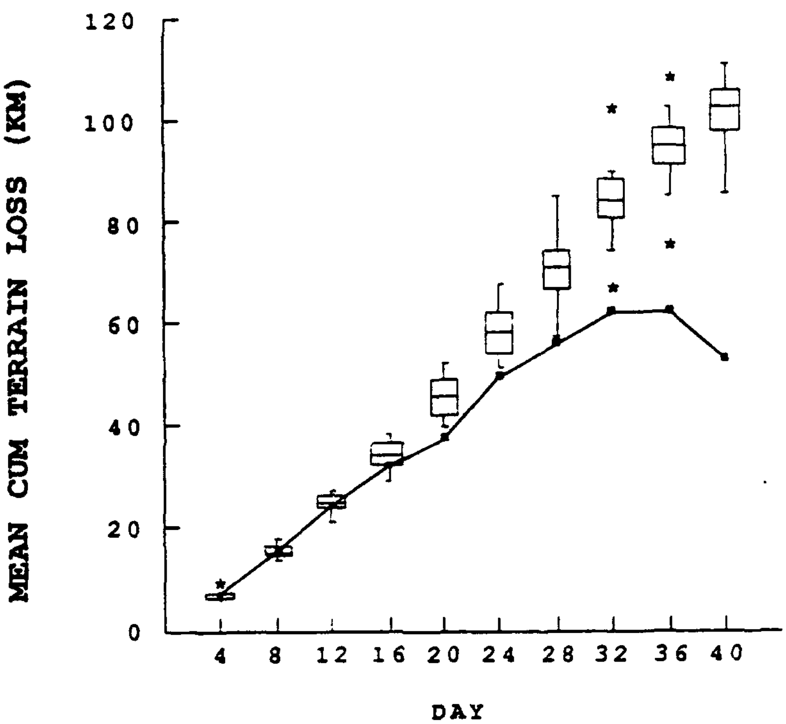

Figure C-1. Cumulative Terrain Lost (km) by Blue Per Minisector, STOCEM Boxplot vs CEM

C-2. TERRAIN LOSS. Figures C-1and C-11 indicate a net gain by Red in all cases through day 40 of the simulation and also show a distribution of STOCEM results having a relatively large variance. In the deterministic CEM result, Blue forces are successful after day 32 in halting Red advances, on the average, and retaking some terrain. However, it can be seen from Figure C-1 that Blue does not halt Red forces, on the average, in any STOCEM replication during the 40 days simulated; rather the net terrain lost continues to increase monotonically in all STOCEM replications. The CEM result is statistically different from the distribution of STOCEM results after day 12 of the simulations, as is evident from Figure C-11..

C-3. PERSONNEL CASUALTIES. The figures (C-2, C-3, C-12, and C-13) showing personnel loss results indicate distributions having relatively small variance. For Blue casualties, deterministic CEM results are fairly consistent with STOCEM results after simulation day 16. Red personnel casualties are significantly greater in the CEM than in the STOCEM, throughout the simulations.

C-4. EQUIPMENT DESTROYED. Figures C-5 and C-15 show that the permanent losses of Red tanks in the deterministic CEM are consistent with those of the STOCEM. Figures C-4, C-6, C-14, and C-16 indicate that Blue tanks and artillery destroyed are significantly fewer in the deterministic CEM than in the STOCEM. Figures C-7 and C-17 indicate that Red artillery destroyed is significantly greater in the deterministic CEM than in the STOCEM.

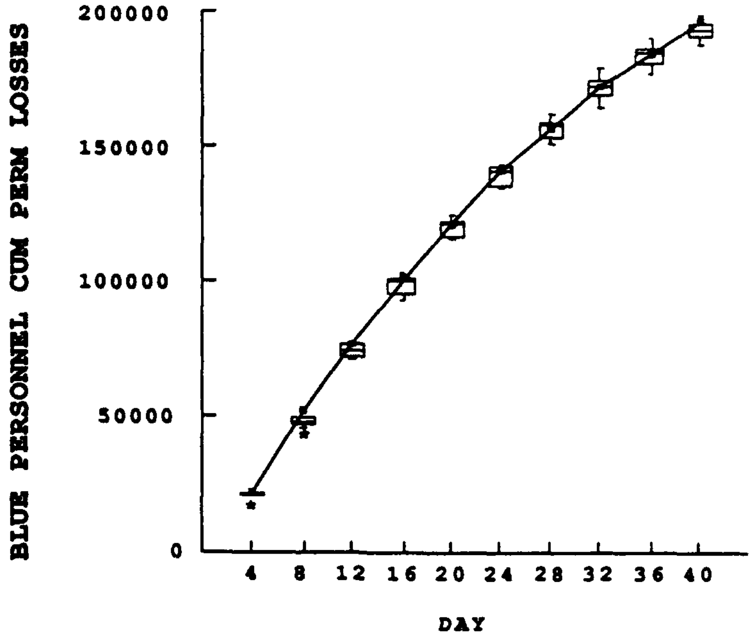

Figure C-2. Cumulative Permanent Losses of Blue Personnel, STOCEM Boxplot vs CEM

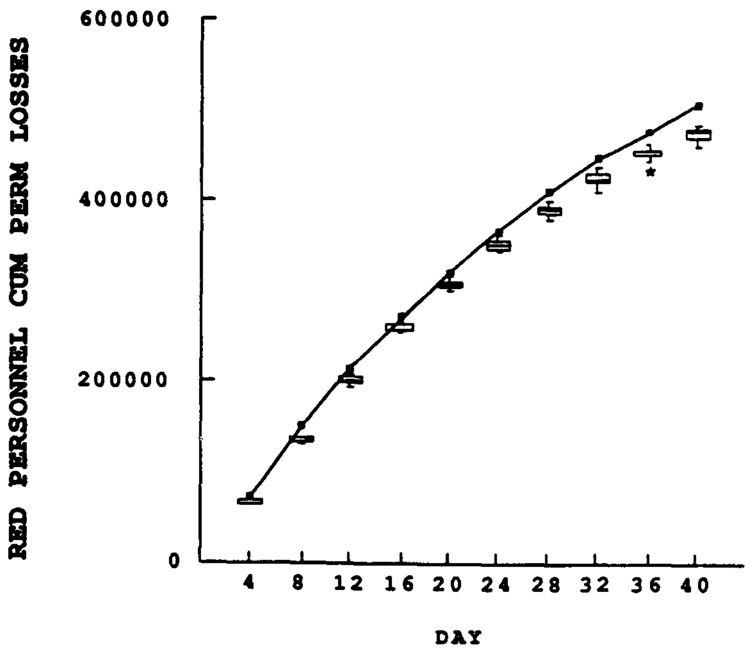

Figure C-3. Cumulative Permanent Losses of Red Personnel, STOCEM Boxplot vs CEM

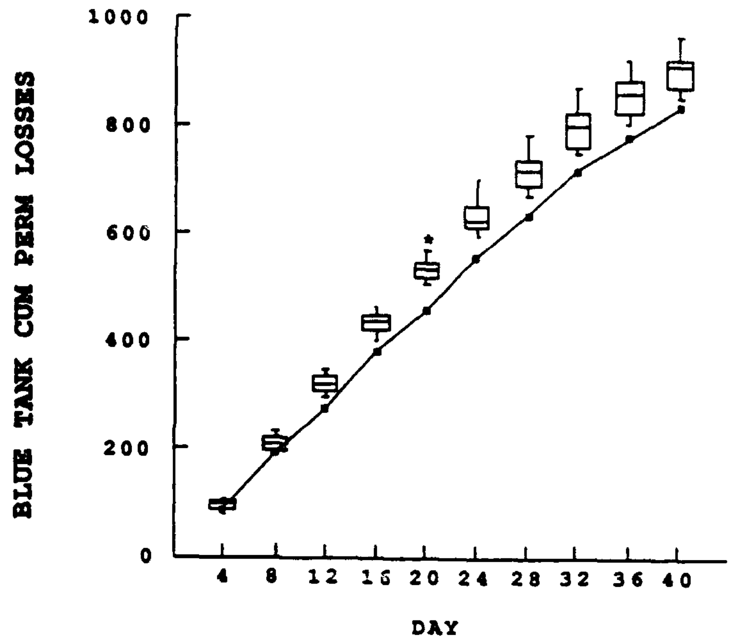

Figure C-4. Cumulative Permanent Losses of Blue Tanks, STOCEM Boxplot vs CEM

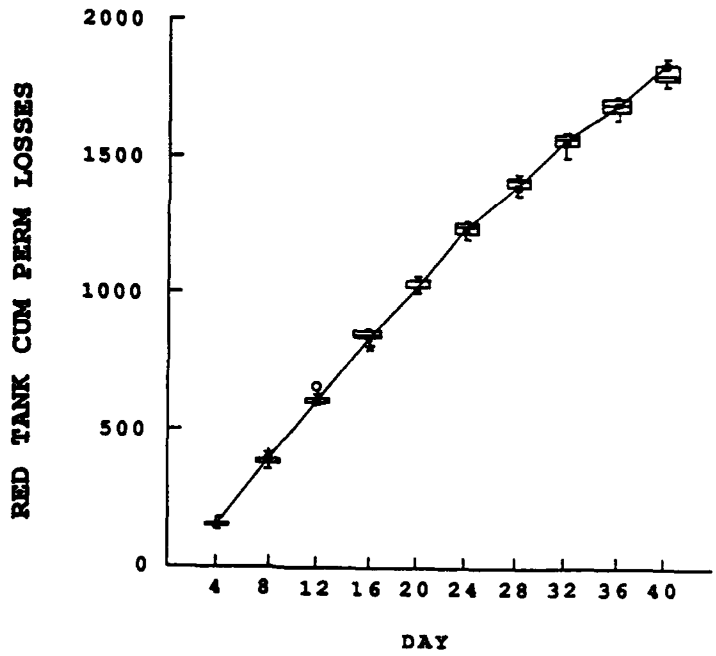

Figure C-5. Cumulative Permanent Losses of Red Tanks, STOCEM Boxplot vs CEM

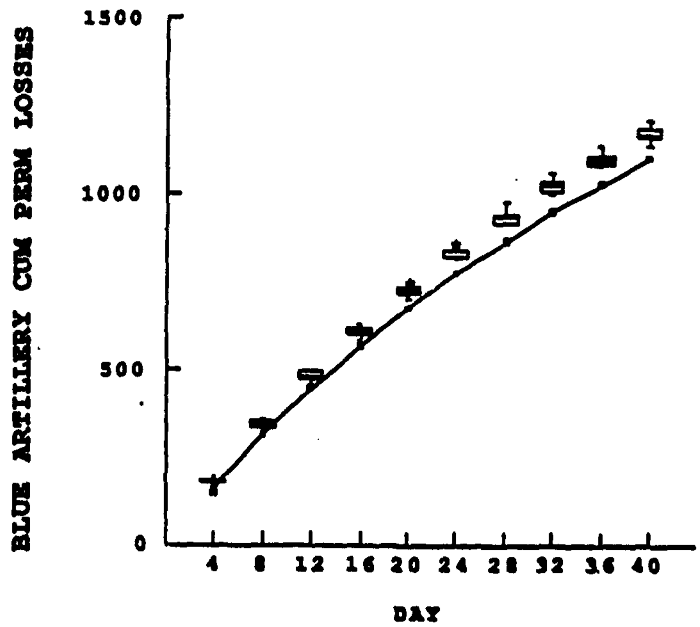

Figure C-6. Cumulative Blue Artillery Destroyed, STOCEM Boxplot vs CEM

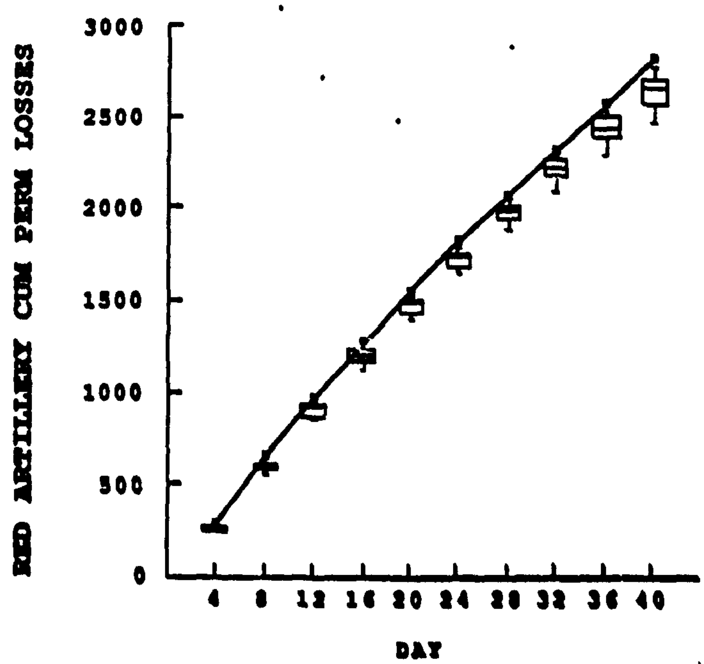

Figure C-7. Cumulative Red Artillery Destroyed, STOCEM Boxplot vs CEM

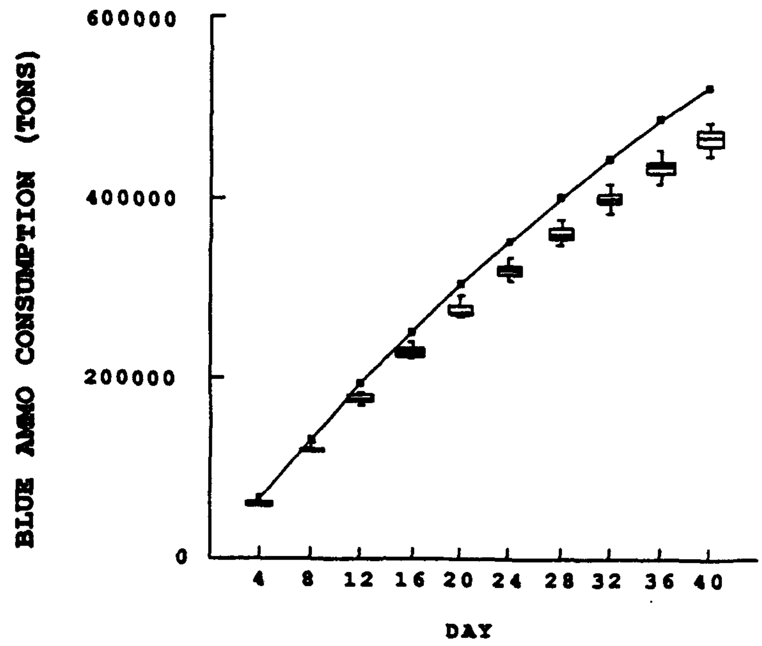

Figure C-8. Cumulative Blue Ammunition Consumed (Tons), STOCEM Boxplot vs CEM

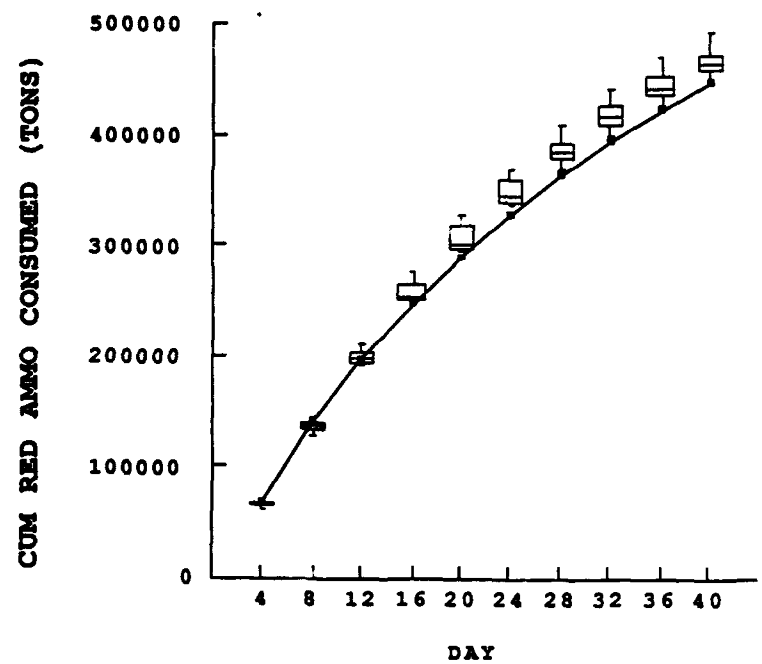

Figure C-9. Cumulative Red Ammunition Consumed (Tons), STOCEM Boxplot vs CEM

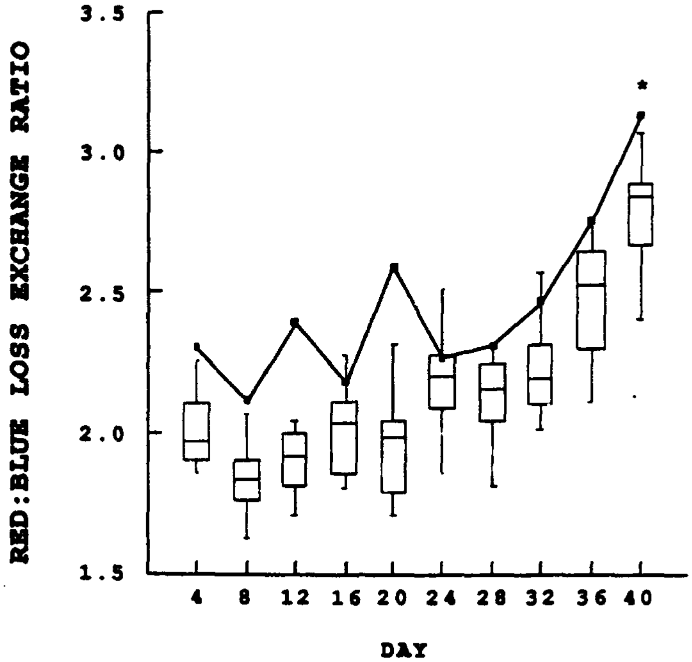

Figure C-10. Red/Blue Major Weapon Loss Exchange Ratio, STOCEM Boxplot vs CEM

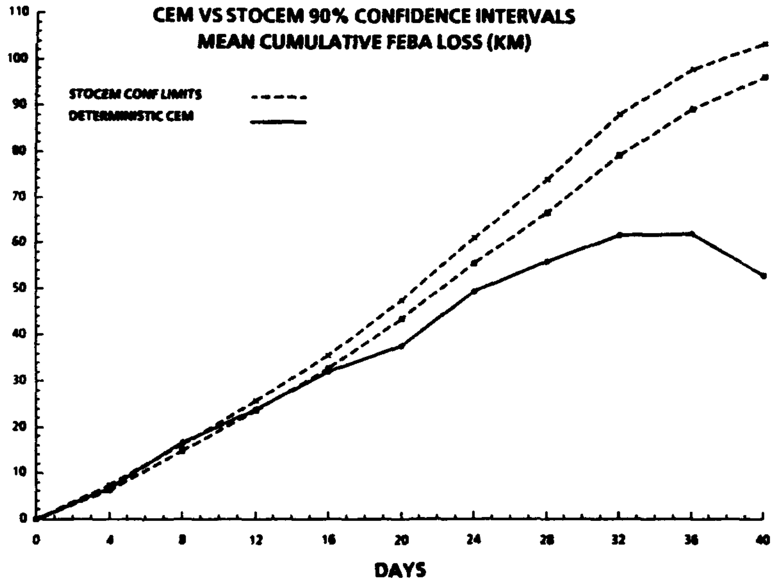

Figure C-11. Cumulative Terrain Lost (km) by Blue Per Minisector, STOCEM 90 Percent Confidence Interval versus CEM

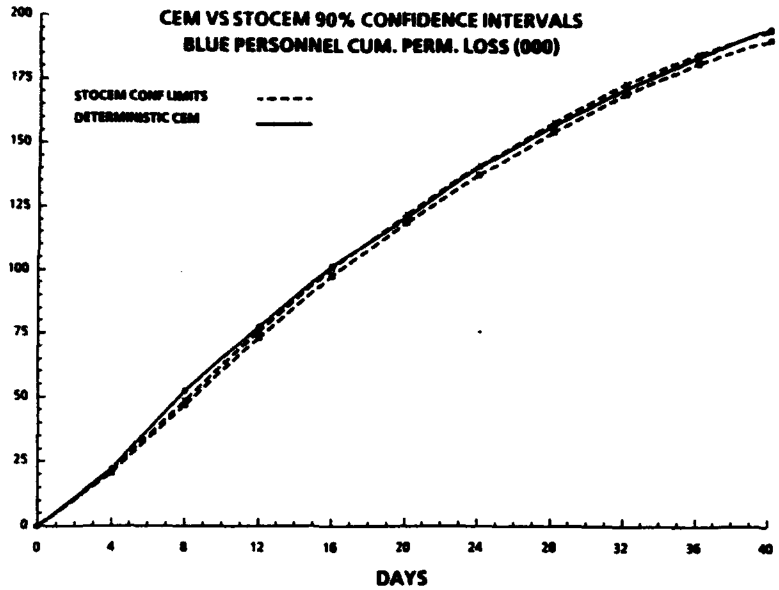

Figure C-12. Cumulative Permanent Losses (thousands) of Blue Personnel, STOCEM 90 Percent Confidence Interval versus CEM

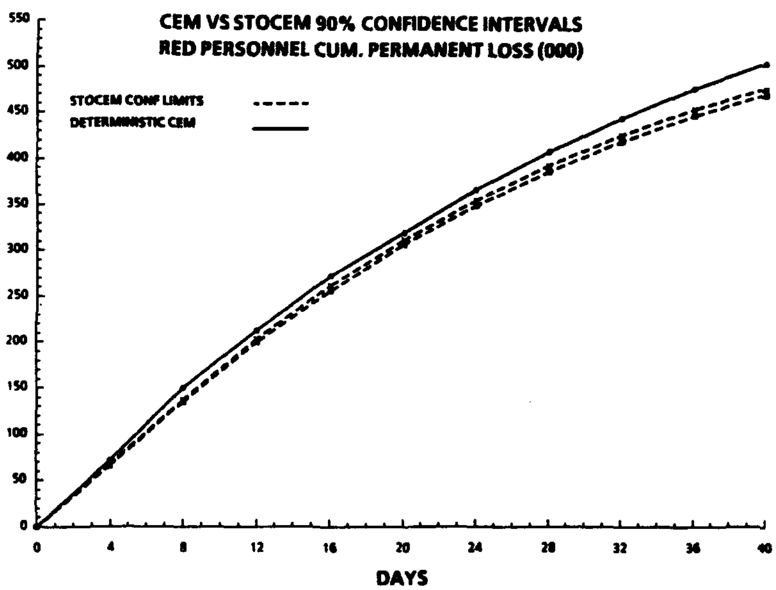

Figure C-13. Cumulative Permanent Losses (thousands) of Red Personnel, STOCEM 90 Percent Confidence Interval versus CEM

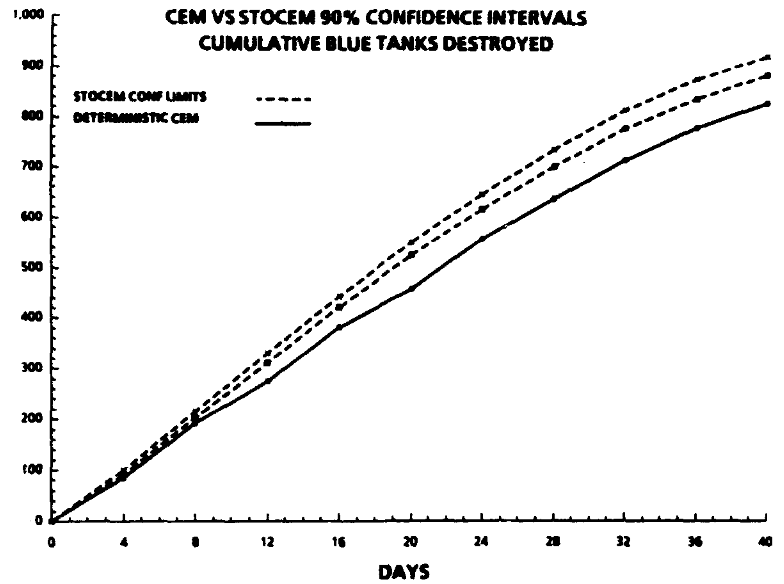

Figure C-14. Cumulative Permanent Losses of Blue Tanks, STOCEM 90 Percent Confidence Interval versus CEM

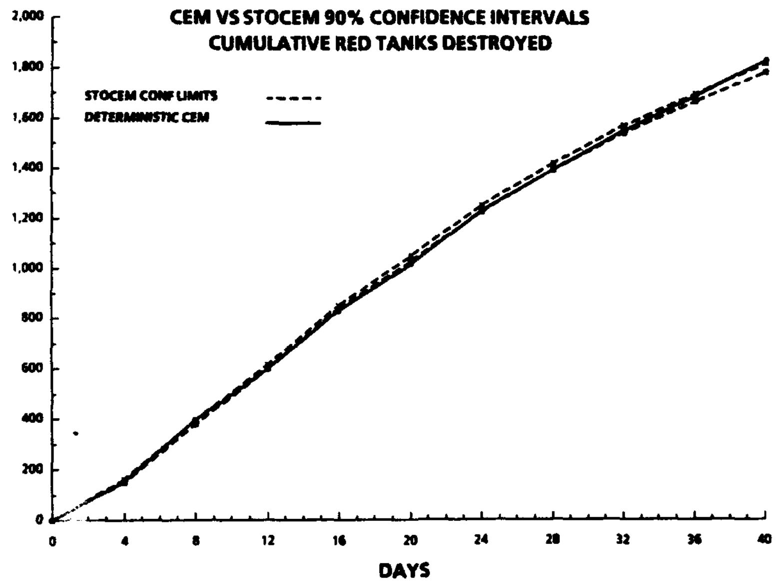

Figure C-15. Cumulative Permanent Losses of Red Tanks, STOCEM 90 Percent Confidence Interval versus CEM

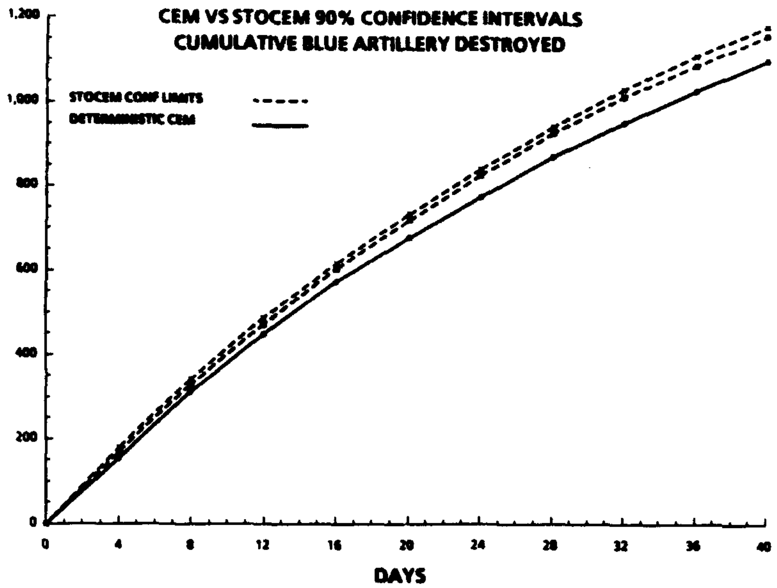

Figure C-16. Cumulative Permanent Losses of Blue Artillery, STOCEM 90 Percent Confidence Interval versus CEM

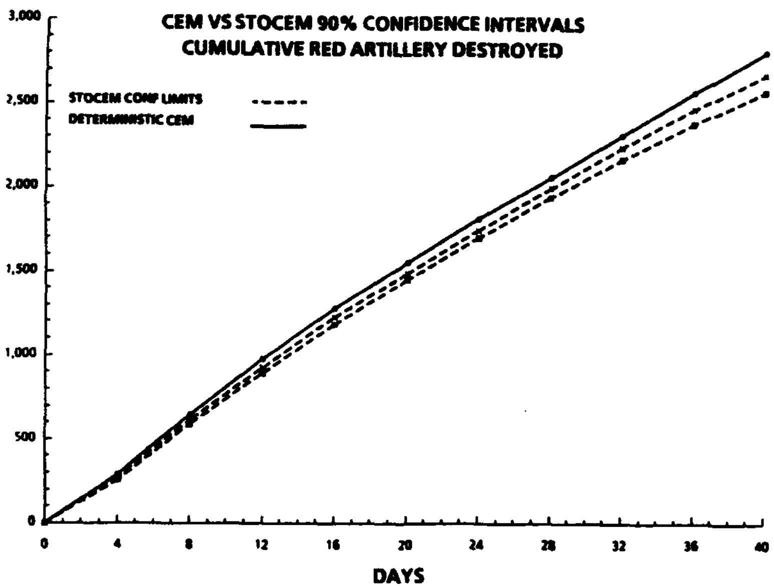

Figure C-17. Cumulative Permanent Losses of Red Artillery, STOCEM 90 Percent Confidence Interval versus CEM

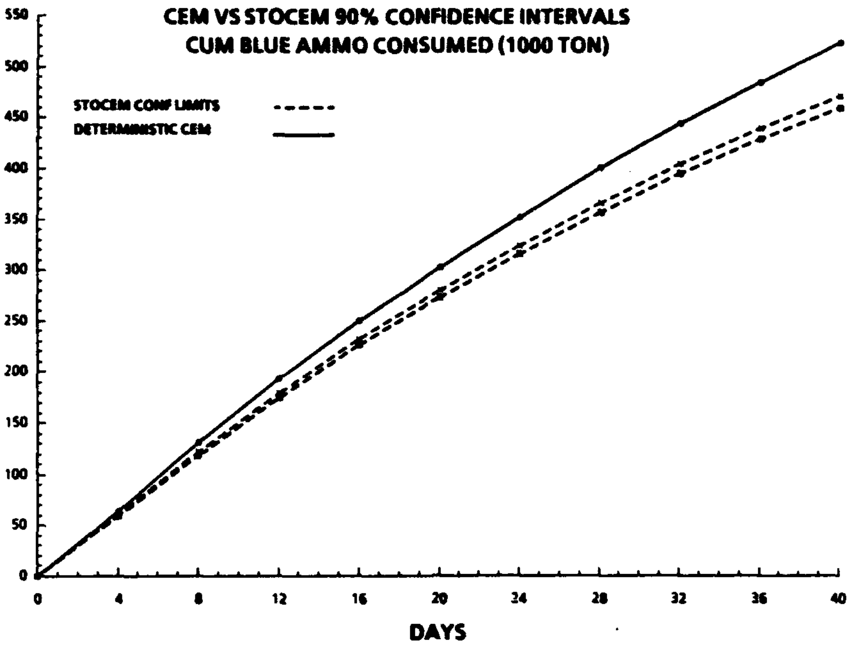

Figure C-18. Cumulative Consumption (tons) of Blue Ammunition, STOCEM 90 Percent Confidence Interval versus CEM

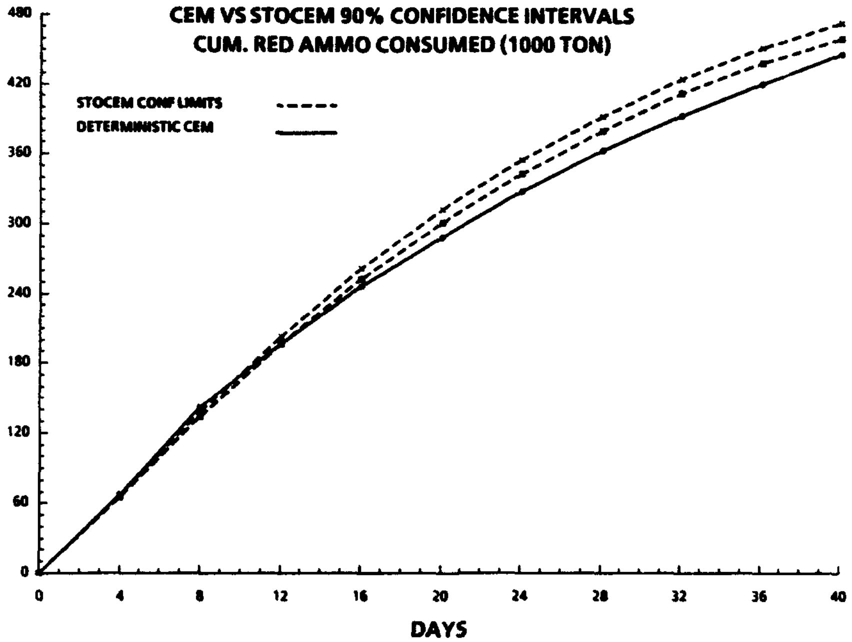

Figure C-19. Cumulative Consumption (tons) of Red Ammunition, STOCEM 90 Percent Confidence Interval versus CEM

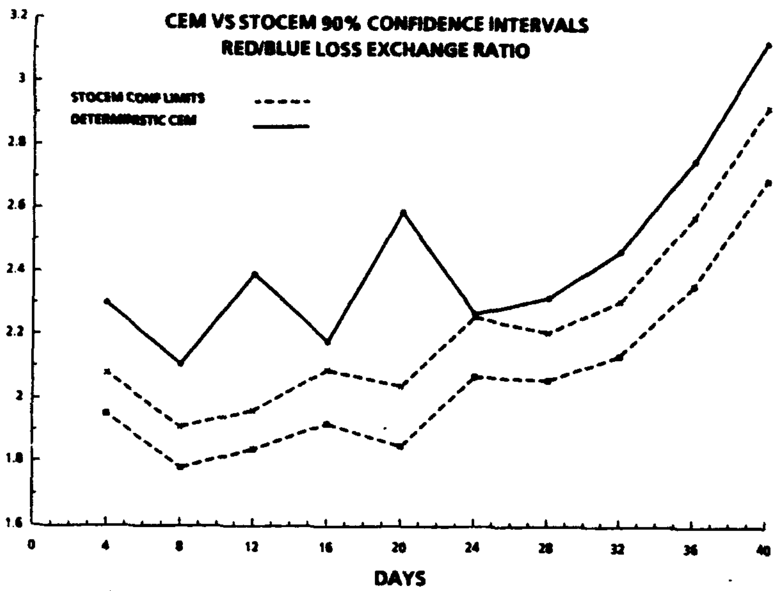

Figure C-20. Red/Blue Major Weapon Loss Exchange Ratio, STOCEM 90 Percent Confidence Interval versus CEM

C-5. AMMUNITION CONSUMPTION. Figures C-8 and C-18 show the Blue ammunition consumption to be significantly greater in the deterministic CEM than in the STOCEM, a consequence of the larger quantities of Blue weapons destroyed in the STOCEM. Figures C-9 and C-19 show that Red ammunition consumption is significantly less in the deterministic CEM than in the STOCEM after simulation day 12, a consequence of the larger quantities of Red artillery destroyed in the deterministic CEM.

C-6. LOSS EXCHANGE RATIO. Figures C-10 and C-20 show that the distributions of STOCEM loss exchange ratios have relatively large variance and that loss exchange ratios are higher (more favorable to Blue) in the deterministic CEM.

APPENDIX D

STOCEM WITH DETERMINISTIC ASSESSMENT OF COMBATATTRITION

D-1. DESCRIPTION OF FIGURES. This appendix contains 20 figures depicting the results of the STOCEM using deterministic assessment of combat attrition, i.e. average combat samples rather than individual replications of the COSAGE. Figures D-1 to D-10 display the 90 per cent confidence intervals of results of the STOCEM using deterministic assessment, shown as solid lines, compared with the 90 per cent confidence intervals of results of the STOCEM with all available STOCEM processes, including the assessment of combat attrition, operating in the stochastic mode, shown as dashed lines. Figures D-11 to D-20 graphically compare the results of the deterministic CEM baseline with the 90 per cent confidence intervals of the twelve replications of the STOCEM using deterministic assessment of combat attrition. Figures D-11 to D-20 show the 90 per cent confidence intervals of the ten selected outcome measures as a function of simulation time, overlaid by a line representing the deterministic CEM result. In Figures D-11 to D-20 the deterministic CEM result is shown by a solid line, and dashed lines show the confidence intervals of the STOCEM using deterministic assessment. All the MOE except loss exchange ratio (Figures D-10 and D-20) are cumulative from the simulation start, rather than the results of a single cycle. For example, Figure D-1 shows the cumulative terrain lost per minisector by Blue, averaged across the theater. The ratios shown in Figures D-10 and D-20 contain the losses during each 4-day period, such as days 1-4, days 5-8, etc.

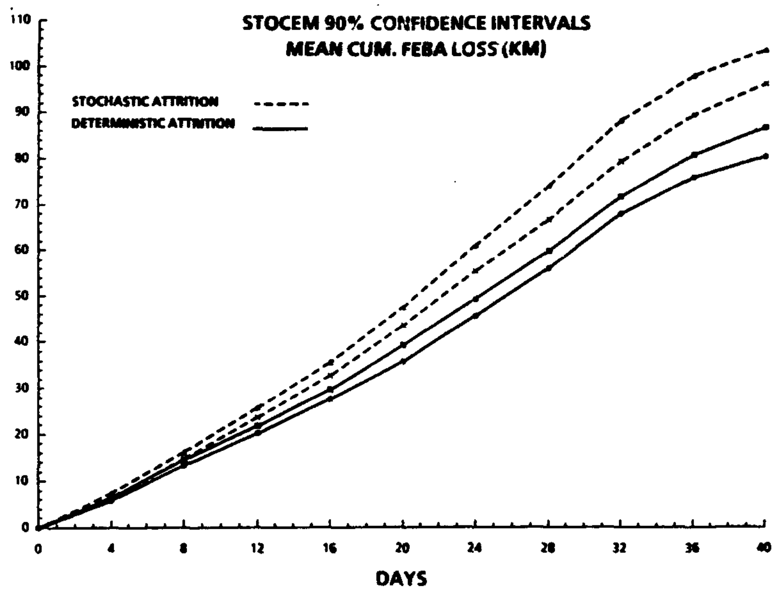

Figure D-1. 90 Percent Confidence Intervals, Cumulative Terrain Lost (km) by Blue per Minisector, STOCEM Deterministic and Stochastic Assessment

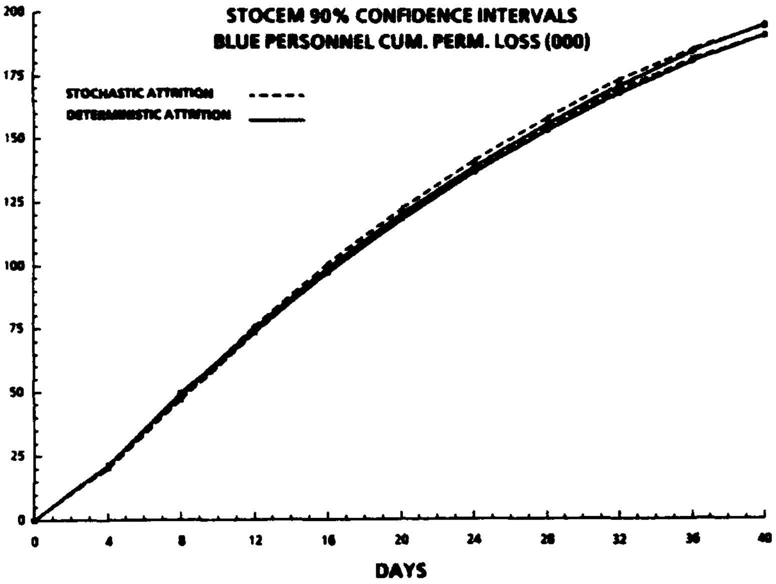

Figure D-2. 90 Percent Confidence Intervals, Cumulative Permanent Losses of Blue Personnel, STOCEM Deterministic and Stochastic Assessment

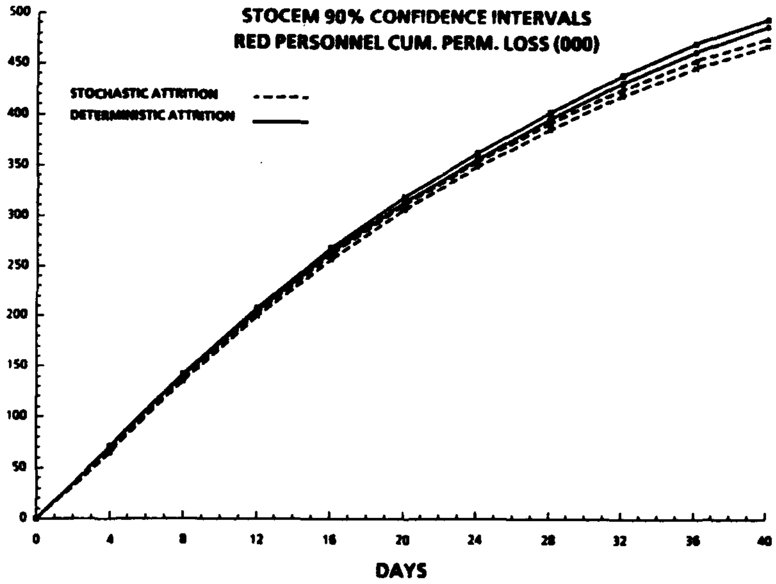

Figure D-3. 90 Percent Confidence Intervals, Cumulative Permanent Losses of Red Personnel, STOCEM Deterministic and Stochastic Assessment

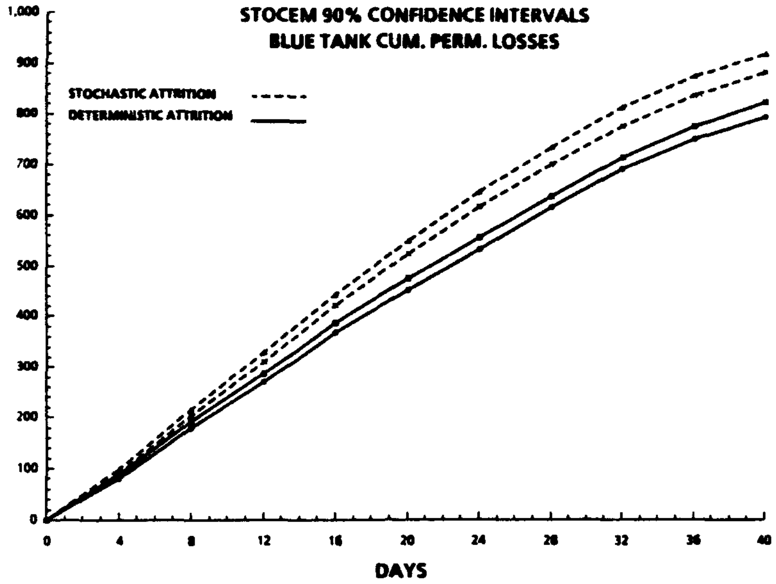

Figure D-4. 90 Percent Confidence Intervals, Cumulative Permanent Losses of Blue Tanks, STOCEMDeterministic and Stochastic Assessment

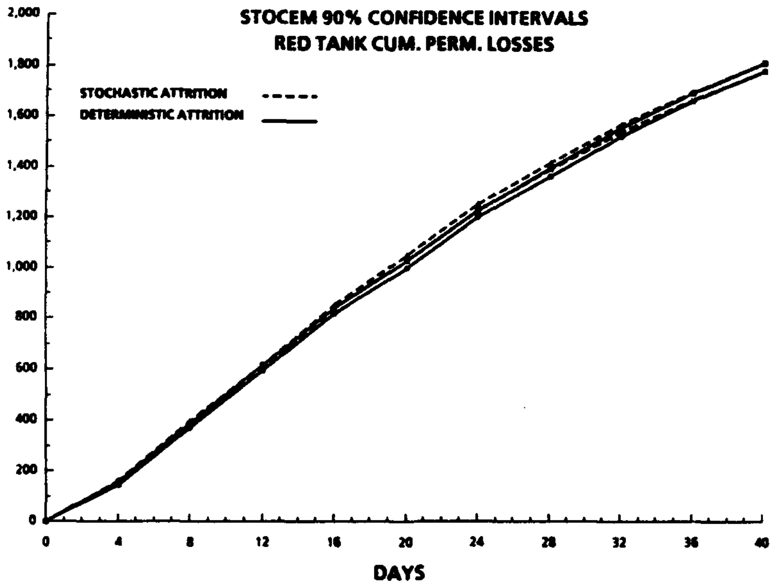

Figure D-5. 90 Percent Confidence Intervals, Cumulative Permanent Losses of Red Tanks, STOCEMDeterministic and Stochastic Assessment

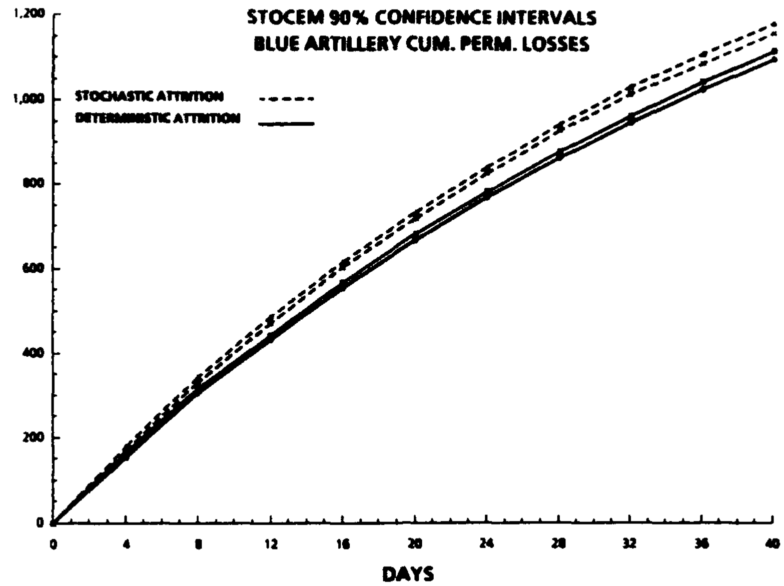

Figure D-6. 90 Percent Confidence Intervals, Cumulative Blue Artillery Destroyed, STOCEMDeterministic and Stochastic Assessment

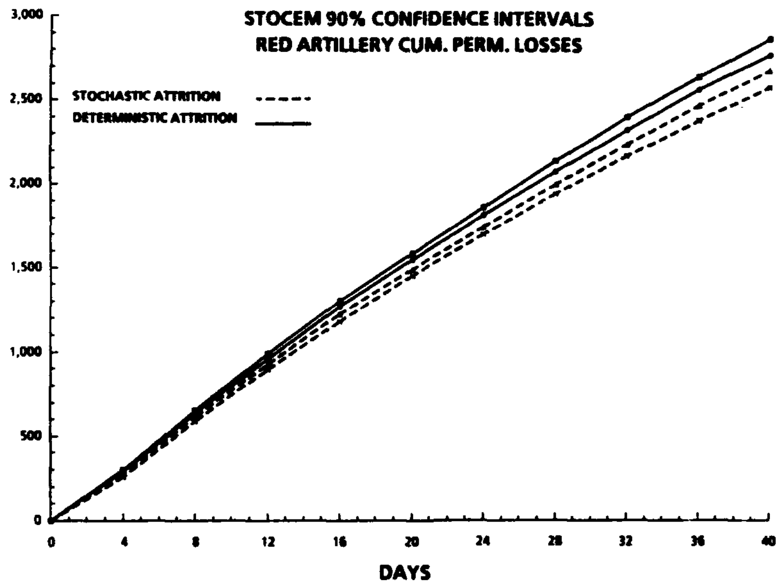

Figure D-7. 90 Percent Confidence Intervals, Cumulative Red Artillery Destroyed, STOCEMDeterministic and Stochastic Assessment

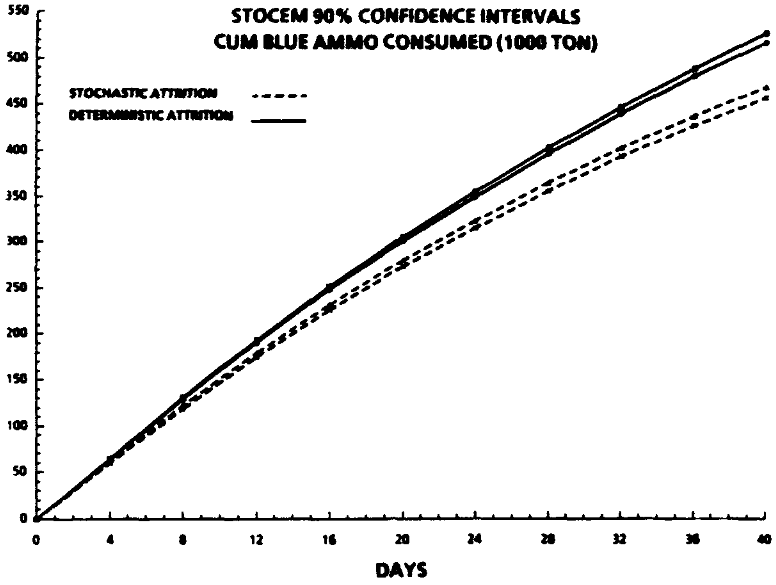

Figure D-8. 90 Percent Confidence Intervals, Cumulative Blue Ammunition Consumed (Tons), STOCEMDeterministic and Stochastic Assessment

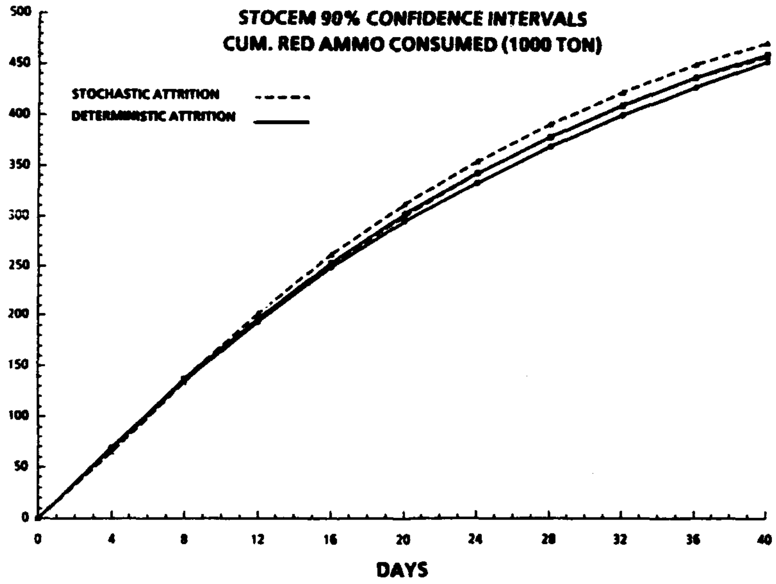

Figure D-9. 90 Percent Confidence Intervals, Cumulative Red Ammunition Consumed (Tons), STOCEMDeterministic and Stochastic Assessment

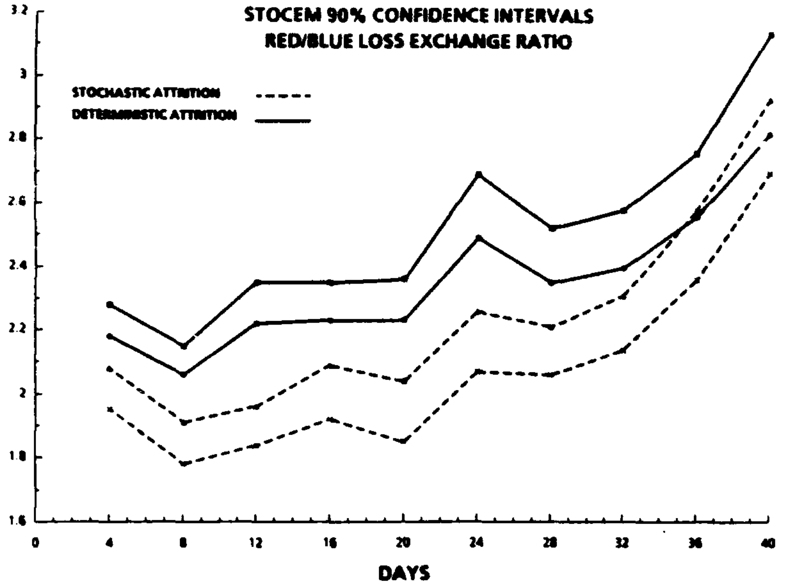

Figure D-10. 90 Percent Confidence Intervals, Red/Blue Major Weapon Loss Exchange Ratio, STOCEMDeterministic and Stochastic Assessment

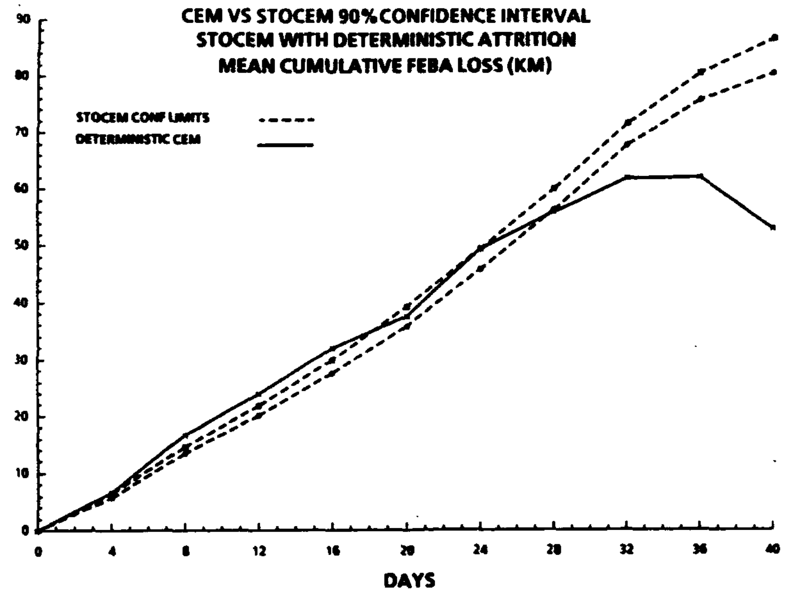

Figure D-11. Cumulative Terrain Lost (Km) by Blue Per Minisector, STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

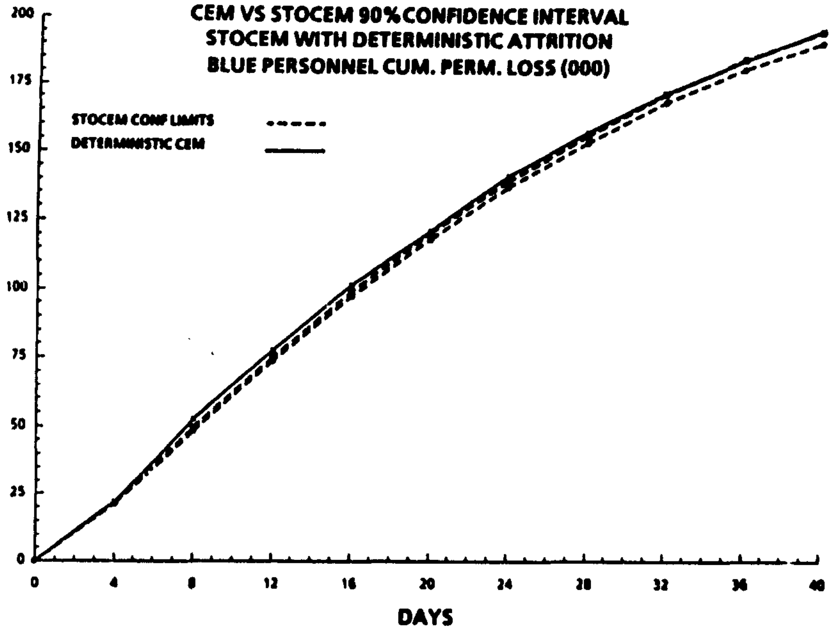

Figure D-12. Cumulative Permanent Losses of Blue Personnel (000), STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

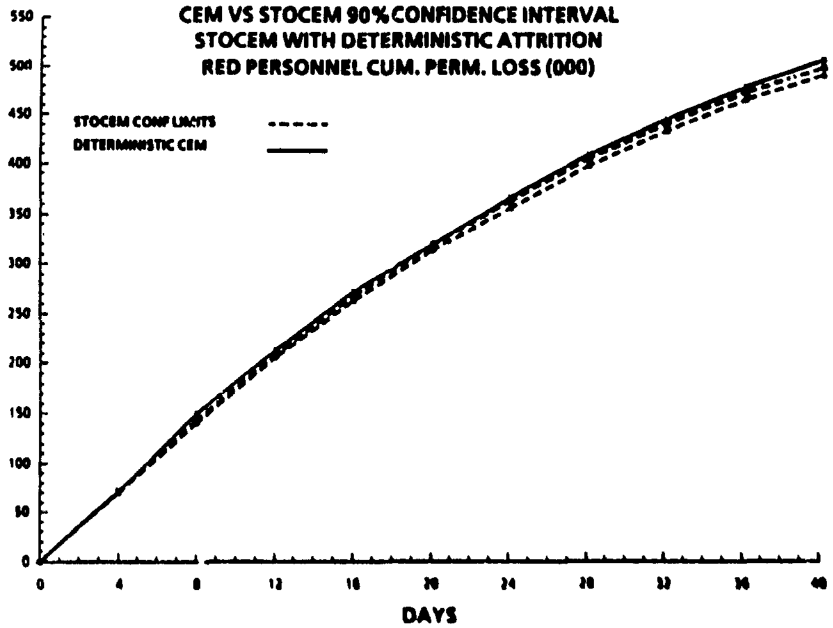

Figure D-13. Cumulative Permanent Losses of Red Personnel (000), STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

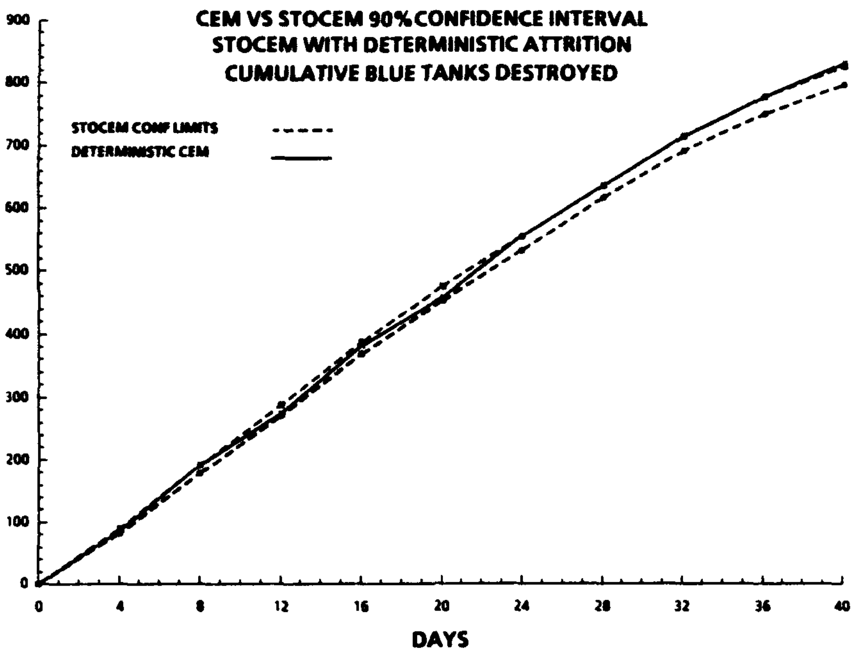

Figure D-14. Cumulative Permanent Losses of Blue Tanks, STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

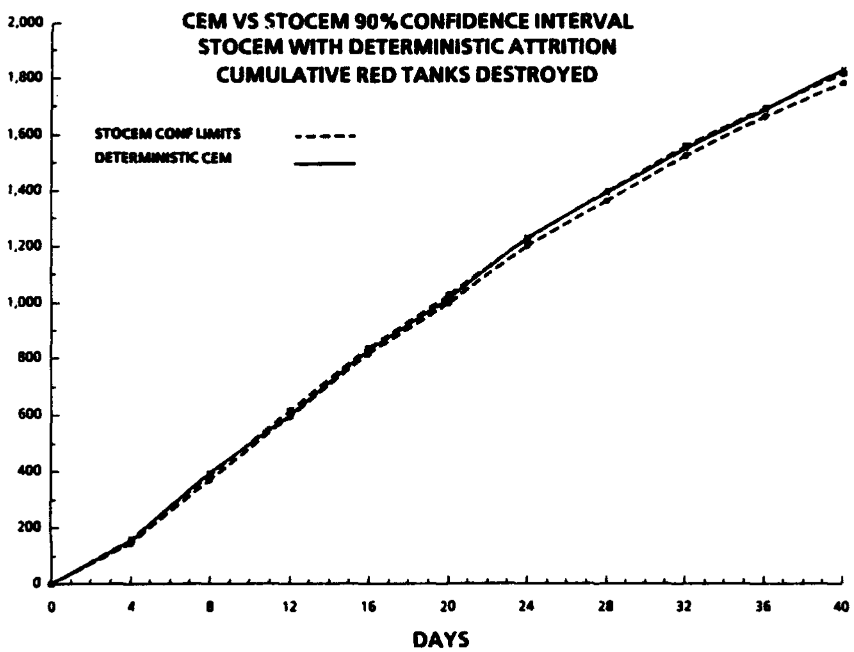

Figure D-15. Cumulative Permanent Losses of Red Tanks, STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

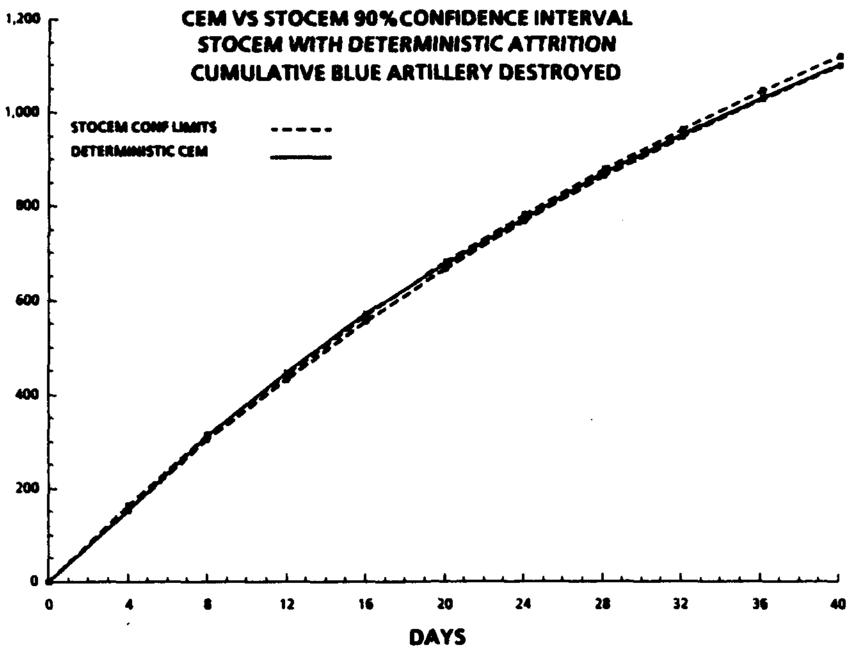

Figure D-16. Cumulative Permanent Losses of Blue Artillery, STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

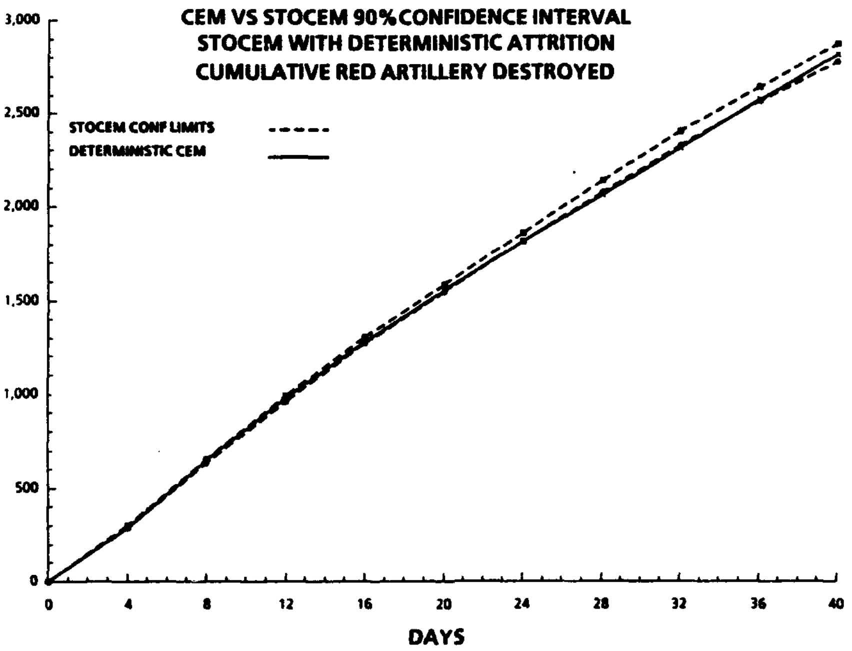

Figure D-17. Cumulative Permanent Losses of Red Artillery, STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

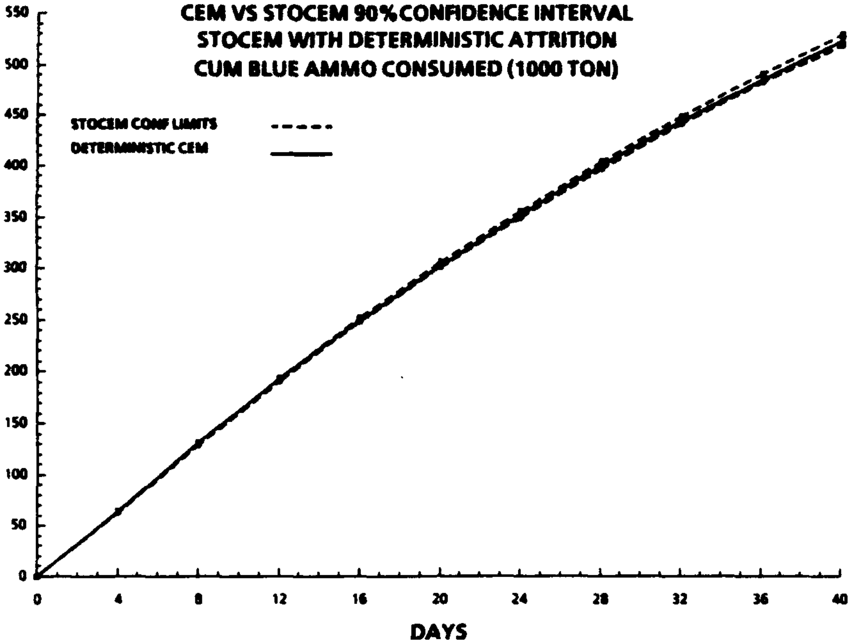

Figure D-18. Cumulative Consumption of Blue Ammunition (Tons), STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

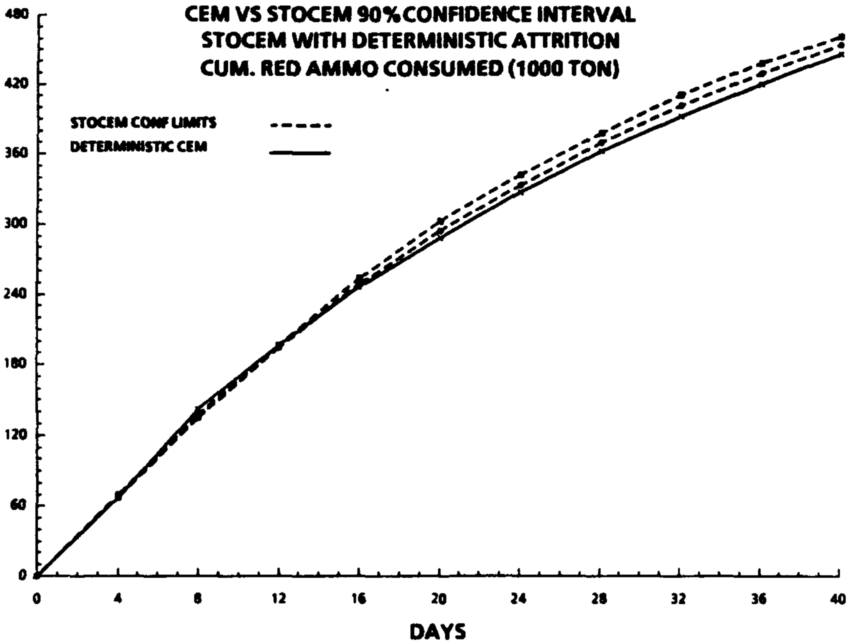

Figure D-19. Cumulative Consumption of Red Ammunition (Tons), STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

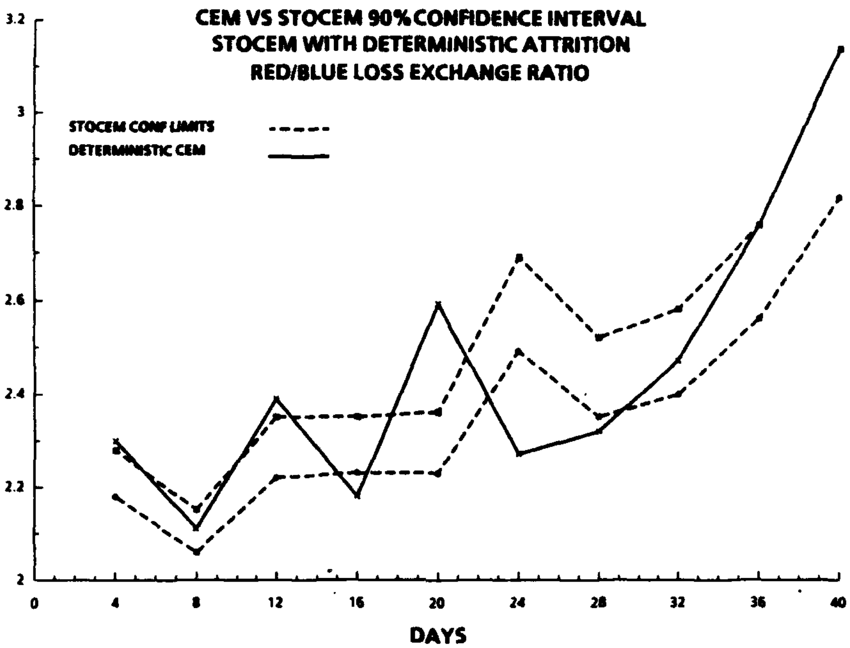

Figure D-20. Red/Blue Major Weapon Loss Exchange Ratio, STOCEM with Deterministic Assessment, 90 Percent Confidence Interval versus CEM

APPENDIX E

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GLOSSARY

ABBREVIATIONS, ACRONYMS, AND SHORT TERMS

ATCAL	the attrition calculation algorithm used to assess combat engagements in the CEM
CAA	US Army Concepts Analysis Agency
CEM	Concepts Evaluation Model
COSAGE	Combat Sample Generator, a stochastic, division combat model that provides the combat samples used by CEM/ATCAL to assess combat engagements
DMZ	the demilitarized zone that separates north Korea from South Korea
EEA	essential element of analysis, a question to be addressed by a research effort
FEBA	forward edge of the battle area
IMSL	a proprietary library of mathematical and statistical computer routines
MOE	a simulation outcome measure, sometimes called "measure of effectiveness"
POLA	Phased Offline Attrition, a system by which an analyst can specify attrition due to nonmodeled effects, to be applied in the CEM to specified sectors at specified simulation times
RAA	Research Analysis Activity, a formal category of CAA project
ROK	Republic of Korea
STOCEM	the stochastic version of the Concepts Evaluation Model